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APPLICATIONS OF SCIENCE

Below is continued the series of articles, begun in the preceding issue, and designed, for general information, to show summarily and simply how science lends a hand in various aspects of common progress. It is intended to issue each of these articles in separate pamphlet form as circumstances permit.

SCIENCE IN EDUCATION

By A. E. E. McKenzie

In the present widespread discussion of education there are two conflicting schools of thought. One stresses social function: '. . . education is not only inevitably conditioned by the limitations of time and place, but should be consciously related to the needs of the particular society of which it is a function.' [1] Another emphasises development of the individual: 'But our belief is that education from its own nature must be ultimately concerned with values which are independent of time or particular environment, . . . no programmes of education which concern themselves only with . . . the immediate adaptation of the individual to existing surroundings can be acceptable.' [2] The disagreement is more apparent than real; nevertheless unless resolved it is liable to exercise a baneful influence on educational progress in the immediate future.

The most significant fact in the modern world, so the supporters of the former view maintain, is that the outlook and structure of our society, both national and international, are changing. Economic ends and motives, for example, tend to be made subservient to social needs; *laissez faire* is replaced by central planning. This evolutionary process can be facilitated by education, or it can be opposed and thwarted. One of its root causes and shaping forces is the advance of science, and hence science must play a vital part in education if progress is to be furthered and efficiently guided.

To this the other school of thought would retort, 'Progress whither?' 'Efficiency for what?' The truly disquieting feature in the world to-day is the instability of values. In some civilised nations the individual has been so completely subordinated to the development of society that he has lost his freedom. Tolerance and even the concept of objective truth were rejected by the Nazis and science itself was threatened. Art was regimented and religion persecuted. The vital need in education to-day is a foundation for conviction and ideals.

It is a commonplace that science played a foremost part in undermining the beliefs and convictions which lay at the basis of our Christian civilisation. The first corrosive conception came from the hands of Galileo and Newton, in the physical synthesis of the seventeenth century, when the medieval outlook finally collapsed and God was banished from inanimate nature. As always there was a lapse of time before the repercussions became widespread. During the seventeenth century the great natural philosophers were all Christians, but by the eighteenth there was a marked change. Priestley records of his visit to Paris in 1774 that he was several times told 'I was the only person they had ever met with, of whose understanding they had any opinion, who professed to believe in Christianity.'

Darwin's publication of the *Origin of Species* in the middle of the nineteenth century marked the beginning of another landslide, and its effects were aggravated in the public mind by fruitless, diehard opposition. Coupled with the highly developed mechanical view of the universe which had not yet revealed its inadequacy, and later augmented by the psycho-analysis of Freud, it gave rise to 'the view that man was fundamentally an animal; that man's ideals were mere passing shadows while his appetites were firm, tangible and eternal forces.' [3]

At first sight this may seem an indictment of science; it may be indeed so regarded, but such a powerful, potentially dangerous, yet liberating force cannot be ignored. There can be no going back to the uncritical spirit of pre-scientific ages. We have tasted of the fruit of scientific knowledge and now that our eyes are opened we must continue to follow as far as we can see.

There are signs that a stage has been reached in which the iconoclastic effects of

[1] Julian Huxley: 'Education as a Social Function,' from *On Living in a Revolution*, p. 181.

[2] The Norwood Report on *Curriculum and Examinations in Secondary Schools*, p. viii.

[3] Michael Polanyi: 'Science and the Decline of Freedom,' *The Listener*, 1 June, 1944.

science are being followed by construction. The intuitional wisdom of the past is being slowly tested, verified, and put on a new basis by the scientific method in psychology and sociology. We are beginning to develop an historical sense in understanding the implications of science and to endeavour to give it its due place and weight in our culture.

Science may have little to say about that perfection of form which gives to a work of art its peculiar power and quality, or of the religious experience which can transform human life ; but the temper and conditions of our time make it imperative that we should seek some correlation between these three main approaches to reality—science, art and religion, and that we should have some clear apprehension of the limitations of each. Only along these lines shall we be able to construct a universally accepted basis for our values and remove that unhealthy duality in our culture, the humane and the scientific. The most pressing and fundamental task of the future is to frame a philosophy of life which incorporates the new spirit and discoveries of science with the inherited wisdom and experience of the past.

The contribution of science to the inculcation of values lies, perhaps, not so much in their inspiration, for that is mainly an intuitive and aesthetic process, but rather in their discipline and rationalisation. In a scientific age religion and philosophy must be capable of a symbolism in scientific terms.

It is essential to disseminate the scientific attitude and outlook among those who do not receive a specifically scientific education, and at the same time, to disclose other traditions of activity, historical, aesthetic and philosophical, to the scientist. Each subject produces its own prevailing attitude, its own outlook and approach to problems, its own dominant sentiments. We speak of the biologist's viewpoint or the historian's outlook. When judgments are made on important issues, there should at least be the recognition that these issues can be faced from several different points of view.

One of the chief defects of present education, particularly in its higher stages, is that owing to the expansion of knowledge it has tended to split up into isolated specialist studies, with the result that the scientist may become little more than a technician, and the humanist may be ignorant of the discipline and achievements of science. It is here that scope for immediate and fruitful advance is most obvious. A new synthesis of humanist and scientific studies to serve as a basis for general, non-specialist education is a pressing need.

The Scientific Content of a General Education

A man of liberal education, whatever his specialist interests, should have some apprehension of science as a whole, its main theoretical discoveries and practical triumphs, its social implications and potentialities for the future. He should understand the methods which have been responsible for its achievements, and its relatedness to other fields of human thought and activity.

To appreciate the significance of science as a factor in civilisation and culture, it must be placed in its historical setting. No great intellectual movement can be understood and appraised without a knowledge of how it arose and how it grew.

At what stage in education this detached view of science should be taught is a controversial question. Two syllabuses have recently been drawn up, one for university undergraduates,[1] and the other for the sixth forms of schools.[2] Both cover much common ground. A few schools have for some years been experimenting with similar syllabuses, and lectures along these lines to intending science teachers are given at the Institute of Education. But as yet practically nothing of this kind for the non-science student has been provided by the universities.

It can be assumed that the great majority of undergraduates or sixth-form pupils have been given a basis of elementary scientific knowledge, and practice in the scientific method by laboratory training, at the pre-School Certificate stage. If now they are to acquire some understanding of the sociological and philosophical significance of science what are the salient outlines of the course they should follow ?

The history of science begins with the Ionian Greeks and the development of generalised thought. The first step in the essentially twofold character of the scientific method, the collection of data by observation and experiment, had, to some extent, been taken by Assyrian and Egyptian mathematicians and astronomers. The second step, the building up of a theoretical structure, was the invention of the Greeks. They took the empirical, geometrical rules of the Egyptians and transformed them into theorems. They put forward hypotheses of the nature of matter and the origin of the universe. They faced for the first time all the fundamental problems of existence and displayed an unsurpassed boldness and fertility in speculation. Where they failed was

[1] British Association Report on Post-War University Education.

[2] Report of Science Masters' Association. To be published in the *School Science Review*, Feb. 1945.

in their unwillingness to subject theory to fact, in the indiscipline of the imagination.

Aristotle realised the handicap of lack of facts and under the patronage of his former pupil, Alexander the Great, organised a widespread collection of biological data which he classified in masterly fashion. And yet, although he was one of the greatest biologists of all time, Aristotle's physics is held up to every schoolboy as the negation of the scientific method. The Greeks indeed laid the foundations, but not for another two thousand years did the complete scientific spirit emerge.

The fundamental phenomenon which marks the beginning of the study of electricity, that amber rubbed with silk will attract light objects, was known to the Greeks. Why did they display so little curiosity and fail to investigate it further? It is possible that the slavery on which their civilisation was based made manual and experimental work undignified and distasteful.

Perhaps an even more potent reason was the fundamental attitude to science and knowledge of the greatest of the Greeks, Socrates and Plato. Whereas the Ionians had looked upon the universe as an organism which grew and evolved from inanimate matter till life and mind emerged (a view very similar to that of modern science), the Athenians regarded nature as created perfect like a work of art, which could be comprehended solely by thought and intuition. They felt no urge to observe and measure the orbits of the planets; they were satisfied that the orbits must be circles because the circle is the perfect form.

The complete absence of any scientific contribution by the Romans, a race of great engineers, with the stimulus of an empire—its varied flora and fauna, its resources to be developed, its diverse and alien peoples—is a curious and intriguing social phenomenon.

The preservation of Greek science by the Alexandrians, and from them by the Arabs during the centuries when the civilisation of Islam eclipsed that of Christendom, leads to the Renaissance and the birth of modern science. But no history of science is complete without some consideration of the Middle Ages, if only to inquire why the acute intellectual atmosphere of scholasticism proved so barren of scientific achievement. When men of scientific temper, like Roger Bacon, arose, their work and influence were stifled by the Inquisition. The outline and framework of philosophy were rigidly fixed by ecclesiastical authority, in contrast to the gradual emergence and shifting of pattern as the pieces are fitted together in science.

The first major contribution by modern science to European thought was made by astronomers. The work and lives of Copernicus, Brahe, Kepler, Galileo and Newton, men whose influence in moulding our civilisation is perhaps greater than any other quintet of their age, should indeed be studied at school both as history and as science; but the full implications of the Copernican revolution and the physical synthesis of the seventeenth century cannot be grasped until the student has reached some degree of mental maturity.

Why did science grow and develop in the sixteenth and seventeenth centuries, while it was still-born in the thirteenth? The surging forces of the Renaissance and the Reformation—the new intellectual spirit, the geographical and economic expansion, the invention of printing—were breaking down the dam of ecclesiastical and ancient tyranny.

The philosopher and prophet of the scientific method, Francis Bacon, who, as Cowley wrote, like Moses from Mount Pisgah surveyed the promised land, was the inspiration of the French Encyclopedists at the close of the next century. The *Novum Organum* urges the dispassionate, inductive method, in a manner academic and unpractical perhaps, since it emanated from the study rather than the laboratory, but nevertheless compelling and illuminating. And coupled with Bacon in our course we should place Descartes, in his rôle of philosopher, the author of *Discourse sur la Méthode*, rather than as mathematician and physicist. Another figure deserving of study, partly as representative of the Renaissance, but mainly because he combined in one personality artist and scientist, is Leonardo da Vinci.

Although the early development of *astronomy* demands an historical approach the later advances may be given more summary treatment. Their fascination is shown by the popularity of the books of Jeans. The scientific picture of the evolution of the universe and its size is a stimulus and challenge to the imagination.

> 'In this interminable wilderness
> Of worlds, at whose involved immensity
> Even soaring fancy staggers.'

That a study of points of light in the sky should result in immense data of the distances, masses, motions, temperatures, compositions and evolution of the stars is a revelation of the astonishing ingenuity and capacity of the human mind.

The survey of the basic science of *physics*, in which the scientific method was first perfected at the hands of Galileo and Newton, has as its leading motif the development of the mechanical view of the universe—

the triumphant explanation of the motions of the heavenly bodies by a single supreme generalisation, the law of gravitation, the remarkable success of mechanics in accounting for the phenomena of heat, and its subsequent inadequacy in the fields of light and electricity. The theory of gravitation represented a complete break with the medieval outlook just as we are beginning to perceive that the theories of relativity and the quantum involve abandonment of the mechanistic materialism of the nineteenth century.

The fundamental theoretical achievement of *chemistry*, the establishment of the atomic theory at the beginning of the nineteenth century with its roots in the speculations of Democritus and the art of Lucretius, represents a triumph of experimental investigation and close reasoning. But the chief significance of chemistry in our course lies in its industrial and economic implications, such as the manufacture of iron and steel and its underlying importance in the social changes of the Industrial Revolution, the increasing use of other metals and alloys, and the economic repercussions of the geographical distribution of deposits and raw materials. Organic chemistry is perhaps the greatest potential factor in industry to-day, with its provision of substitute materials, dyes, drugs, plastics and fuels. The chemist, too, is slowly closing the gap between inanimate and living matter, the centre of interest at present being in the giant molecules of the viruses.

Technology has a claim to be considered as a cultural field of its own, and the vital importance of pure research and technical advance constitutes an essential topic of our course. To put the Machine Age in its proper perspective its achievements must be related to the technical discoveries of the Stone, Bronze and Iron Ages. The history of transport and communication, the development and exhaustion of sources of power, and the replacement of the man by the machine, call for consideration. They involve a discussion of the social effects of technological changes, such as the reduction of drudgery and want, the distribution of population, the problems of leisure, and the pollution of environment. Some students will be interested to study the influence of science and the machine on modern art and craftsmanship.

Biology as compared with the physical sciences, is still undeveloped and immature, but the problems with which it deals have a more immediate relevance to human life. Its great generalisation, evolution, has now so coloured our outlook (or, indeed, should have done so), and has so many ramifications in other spheres of thought, that it is desirable that the diverse lines of evidence on which it is based should be examined and understood. The accepted fact of evolution and theories as to its cause are not always clearly distinguished by the layman.

The history of the establishment of Darwin's theory involves the relations between science and religion. T. S. Huxley claimed that a new reformation should succeed the new biological renaissance. While this has not yet occurred, his grandson is a foremost exponent of evolutionary ethics.

To the problem of the differential birthrate and the decreasing national population biology has its own specific approach and contribution for solution. It marshals evidence for and against sterilisation of the unfit, a measure compulsory in Germany, and recommended as a voluntary practice in England by a Royal Commission. It has a decisive answer to the nonsense talked about race and the superiority of the Nordics.

The rulers of a world empire should be familiar with the scientific progress made in the conquest of tropical diseases, the control of insect pests, diet and dietary deficiencies in different parts of the empire including their native land. They should be aware of the possibilities of the creation of new plants and the breeding of new animals to live under particular conditions and resist diseases, of the dangers of soil exhaustion and erosion.

Besides all these practical biological problems there is the immensely significant controversy between the mechanist and the vitalist—the mechanist who believes that the principles of physics and chemistry are the ultimate basis of biology, the vitalist who believes that new fundamental principles, embodying perhaps some kind of purpose, are yet to be found.

Geology, like biology, presents for a background to human history a vast wilderness in time of slow but enormous changes :— repeated invasions of the land by the sea, the creation of mountains and continents, extreme variations of climate.

Many would deny that *psychology* has a claim to be considered as an established science since it has no body of universally accepted theory. Nevertheless it has won practical triumphs in the realm of intelligence testing, in the treatment of mental defectives, and in the remedial treatment of psychoses. Different schools of psychology may conflict, but their subject matter is of such importance as to deserve close scrutiny. We have mentioned earlier the wide influence of Freud ; it is desirable that the educated man should know how far the Freudian theories have stood the test of further investigation and research.

The studies of primitive cultures and re-

ligions in *anthropology* and of the types of human association and organisation in *sociology* have made considerable strides in recent years, and their contribution to an objective view of our civilisation is steadily increasing.

The Universities

The provision of a new synthesis of humanistic and scientific studies is a primary task of the universities.

The British Association Report on Post-war University Education advocates the institution of honours and pass schools of 'Philosophy Natural and Social' whose ultimate aim would be 'to construct a system of ideas which bring the aesthetic, moral and religious interests into relation with those concepts of the world which have their origin in natural science.' [1]

During the first two years the course would consist of a survey of science including experiment and observation. In the last year this would be linked with a study of philosophy, from Plato to modern times. A broad university course of this nature would be a better preparation for the majority of teachers than the present science honours schools.

Dissatisfaction with the inadequacy of the present narrow, specialist courses in producing leaders of character and vision has already been widely expressed both in this country and America, and has led to proposals for radical reform. A suggestion has been put forward, for example, that the basis of all university courses should be a study of great books, the classics of thought and literature from ancient Greece to modern times. That such a course could have a broadening and quickening influence on science students there can be little doubt, but it would need to be supplemented for them, and even more so for arts students, by a broad survey of science.

The British Association Report on Post-war University Education advocates 'Science for All' at the university, and recommends a course similar to that already outlined. It suggests that students might be grouped in accordance with their specialist studies under a class leader who would endeavour to introduce and guide their discussions to make the maximum number of direct contacts with their interests. Two weekly evening lectures by experts in different branches of science would be attended by all the groups, each of which would later discuss the topics of the lectures, amplifying and emphasising whatever it found of the greatest interest.

[1] Whitehead, *Process and Reality*.

Adult Education

The paradox of education is that, for the great majority, it comes to an end before its value and relevance to life can be appreciated. The child at school is too immature and has too little experience to be interested in the social, economic and political issues of the age. These interests develop in adult life and the full fruition of early schooling is not possible without adult education.

Increasing facilities exist for self-education, excellent county and borough libraries, the radio and the not always unworthy stimulus of the film and newspaper. But the wise and efficient use of these facilities presupposes an unusual educational foundation, and an abnormal singleness of purpose. Moreover discussion and argument, the direct exchange of mind with mind, is lacking, and also the co-ordinating direction of the teacher. One of the most needed educational advances, therefore, as Sir Richard Livingstone has so cogently argued, is a considerable increase in adult education.

The main agencies for the provision of non-vocational adult education are the Extra-Mural Departments of Universities and University Colleges (originating in the University Extension Movement of 1873), The Workers' Educational Association (founded in 1903), and the Local Education Authorities, who have been responsible for recent developments such as the literary institutes in London, and the village colleges in Cambridgeshire.

The Ministry of Education published regulations and began to give grants for adult education in 1924. The highest type of course for which a grant is offered is a tutorial class, organised by the extension boards of the universities, lasting for three years, of approximately university honours degree standard. Classes of two hours are held at least once a week for 24 weeks a year. There are also one-year, one-term and vacational courses which may be university tutorial or W.E.A. classes.

The part that science at present plays in these courses is small, as will be seen from the following extract from the British Association Report on Science Teaching in Adult Education, 1933.

> 'Statistics collected in the course of the present inquiry show that there is still a strange neglect by adults of this branch of study, compared with such subjects as Literature, History and Economics. The number of Science Courses is not more than approximately 6 per cent. of the total number. . . . The Extra-mural Department of London reports: Out of a total of 1009 courses and classes in the

years 1926 to 1932 only 41 were on science, viz. Biology 19, Anthropology 15, Astronomy 3, History of Science 2, Physiology and Hygiene 1, and one course of a general character, Science and Daily Life. The average attendance at the courses was small. In University Extension Courses in general, an average attendance of 60 to 70 is usual in the London district; but for science courses within the same period named it was less than 40. The limited interest shown by the public, even when a science course is provided, undoubtedly discourages Local Committees responsible for the organisation of University Extension Courses from choosing this subject.'

The evidence of those engaged in adult education suggests that many adults have learnt little science at school and they are intimidated by the imagined difficulty of the subject and its remoteness from everyday life. The adult mind is interested in generalisations and principles rather than data, in the human and social applications of science rather than its technical and theoretical achievements. The presentation of science in this form calls for exceptional qualities in the teacher and there is a lack of tutors with a wide experience of life and interests outside science.

The type of course which seems to be called for is very similar to that we have already outlined. But there is the difficulty and complication that many adult classes have no background of knowledge of elementary science on which to build. This necessary basis requires incorporation in the course. And here difficulties of equipment and apparatus arise. Many classes are held in village schools where even gas and water are not available. Tutors are often obliged to bring their equipment by car and to perform experiments using a spirit lamp and a bucket of water.

It has been suggested that the number of residential colleges in this country should be increased until the provision is equal in scale to that of Denmark—that is to say, 'one people's college for 150 men and another for 100 women among every half million of the population.' Country houses, which their owners can no longer afford, could be purchased for the purpose and it is estimated that the annual cost would be £2,500,000 or an addition of about 6*d.* in the pound to the pre-war cost of the national educational budget.

The training given at these colleges should consist of that judicious blend of humane and scientific studies which we have advocated earlier, with the aim of inculcating a wide, progressive and balanced outlook, and some understanding of the major intellectual and sociological forces in our civilisation.

How far the majority of the population is mentally fitted to follow such studies is a problem for future research. No doubt there are many whose main cultural development can come only through vocational, technical and manual activities.

Science in Schools

The teaching of science to boys and girls in schools presents a very different problem from that of its teaching to university undergraduates and adults. Adults are interested in the application of science to their experience of life, and in its generalisations. The schoolboy has little experience of life and not until his later adolescence does he begin fully to appreciate the value and economy of principles and generalisations. On the other hand at the outset of his secondary school career (about 11+) he brings a refreshing and animated curiosity in the world around him and an urge simply to collect information. He has a lively interest in the application of knowledge and is a convinced utilitarian. His power of abstract thought, his ability to distinguish the significant from the trivial, his appreciation of logical development, grow gradually and mature to a pitch depending on his inherent ability. Sir Percy Nunn has divided the boy's mental development into the wonder, utility, and system stages, paralleled by Whitehead in the rhythms of romance, precision and generalisation.

We no longer believe, however, that mental abilities emerge suddenly and in series, a theory which once, supported by the prestige of Stanley G. Hall, had some influence on educational practice, but that there is concomitant development and gradual, continual, mental growth. Thus while using to the full the wonder and utilitarian urges of the boy we must endeavour to cultivate his command of theory. Indeed one of the most important functions of a secondary education is to train a boy in the power of abstract thought.

The advent of universal education has necessitated a process of differentiation—the provision of separate schools for pupils of different abilities and interests. The Education Act of 1944 provides for three types of secondary schools, grammar schools (the old secondary schools), technical high schools and modern schools (the old senior schools). The science taught in these different schools calls for different treatment, emphasis and approach. Science teaching in grammar schools has a longer history and has been far more widely and closely discussed than in

the other types of schools and hence we shall consider this first.

Grammar Schools

The aims of science teaching in grammar schools may be subdivided into informative and disciplinary. This arbitrary dualism is convenient but it may be misleading, unless examined critically, like the problem of form and content in art. In the early history of school science teaching too much stress was laid on the disciplinary objective and the courses were narrow and intensive; to-day there is an apparent trend in the opposite direction, although the argument for the training in scientific method has lost none of its force.

Mr. H. G. Wells, in his address on 'The Informative Content of Education,' [1] argued that the school curriculum should provide a scientific world picture in space and time, following very much his three outlines, *The Outline of History*, *The Science of Life*, and *The Work, Wealth and Happiness of Mankind*. The underlying conception is already being applied in the schools, as we shall see, in the teaching of General Science. But its danger is emphasised by a remark made by Gorst in another context: 'Facts should be regarded as poisons, to be used sparingly and with discrimination. . . . There should be no such thing as instruction in the sense which implies the cramming of the brain with information.'

When, from the wide field of scientific knowledge a syllabus for schools is selected, is should, in the words of the Hadow Report, 'be thought of in terms of activity and experience rather than of knowledge to be acquired and facts to be stored.' The adult has a core of living experience to which he can relate new facts and ideas, but the schoolboy is in process of forming his. The school, therefore, should not attempt to teach too much, and what is taught should continually be tested, thrown into fresh combinations and used. No doubt one of the best safeguards against the danger of 'inert ideas' is to construct the syllabus as far as possible round basic principles.

This method was used in the framing of the General Science syllabus of the Science Masters' Association.[2] Lists were drawn up, one of fundamental scientific principles and another of the scientific interests and contacts of a boy in his everyday life, and the two were fitted together.

We may summarise the objects of the informative content of the science course in the grammar school as being to provide a scientific understanding of the pupil's environment and his own body, and to teach the elements or grammar of science to serve as a basis for further scientific education whether technical, university or adult.

The disciplinary objective of science teaching is to do something of permanent effect to the pupils' minds. Forty years ago it was thought that this was a comparatively automatic process and that science, by virtue of its nature and form, was peculiarly suited to training particular mental faculties such as observation and reasoning powers. But the faulty psychology on which this was based has been discarded, and psychologists deny the existence, for example, of a faculty of observation. The act of observation cannot be divorced from what is observed and the process of training in observation consists largely of inculcating a knowledge of, and interest in, the particular material to be observed.

Numerous experiments in America and this country have led to the conclusion that the training which can be transferred from one subject to another consists of concepts of method and ideals of procedure. In order to be rendered transferable they must be made conscious in the minds of the pupils; they should be tinged with emotion so that their value is consciously acknowledged and welcomed. In other words, good sentiments, 'the organisation of emotions round an object or idea,' should be built up. American psychologists call this the building of emotionalised attitudes, and the old-fashioned schoolmaster, character training.

The concepts of method and ideals of procedure which science can teach may be summarised as the scientific method and the scientific temper. The quintessence of these is an intellectual honesty, a critical, sceptical, almost truculent attitude to all 'facts' until verified. Scientific facts are clear cut and verifiable; therein lies the strength and weakness of science as a discipline. Scientific fact and hypothesis too are sharply distinguishable. Contrast with this the difficulty of disentangling fact and opinion, coloured perhaps by prejudice and subconscious motive, in a political argument.

Any subject, studied to university standard, should produce integrity of mind. It is the peculiar virtue of science that its discipline may be presented in a simple and direct form at a comparatively early stage. An educated man, says Sir Richard Livingstone, is a man who can tell when a thing is proved. The foundation, at least, of such ability can best be laid by a training in science.

The most extreme exponent of the disciplinary aim of science teaching was Henry Armstrong (1848–1937), professor of chemis-

[1] British Association *Report*, 1937, p. 237.
[2] *The Teaching of General Science*. Science Masters' Association, 1936.

try at the City and Guilds Institute, South Kensington, who developed the heuristic method of teaching boys chemistry. 'Heuristic methods of teaching,' he said, 'are methods which involved our placing students as far as possible in the attitude of the discoverer—methods which involve their *finding out* instead of being merely told things.' The boys were given problems to solve for themselves in the laboratory. Armstrong did not believe in lectures. In his youth, he said, 'listening to lectures produced little abiding effect, one image following the other too quickly.' He spoke of 'our old foe, the dogmatic teacher,' and recommended the study of the detective stories of Edgar Allan Poe and Gaboriau to teachers and students of science. There is no doubt that he had a great and beneficial influence. The extreme form of heurism which he preached, however, has been compared to taking a non-swimmer to the bath and throwing him into the deep end, with the injunction to teach himself to swim. A word denoting 'search' rather than 'discovery' would better have described Armstrong's method; the average boy can discover little for himself.

A virtue of science as a school subject is that it deals with concrete facts which may be obtained and verified at first hand and not necessarily through the medium of books and authority. There are still many grammar schools inadequately equipped with apparatus; they lack such elementary and fundamental instruments as ammeters, voltmeters and microscopes. There are even more schools inadequately staffed with laboratory assistants. The time and energy of the science teacher, which should be devoted to preparation and the trying out of new experiments and demonstrations, is expended in setting out and putting away apparatus, in cleaning and repairs. A laboratory assistant who is a skilled mechanic can make a great deal of the apparatus required in schools more cheaply than it can be bought. The size of classes militates against efficient practical work. Classes of 30 or even 40 are not uncommon, whereas 20 should be regarded as maximum.

The natural descendants of the heuristic method is the problem method. It is associated with class demonstration rather than laboratory work. There has been in recent years a trend away from laboratory work, perhaps too strong a trend, partly as a reaction against the time which was once needlessly wasted in numerous stereotyped measurements in the laboratory, and partly to enable teachers to proceed more quickly and cover more ground.

The essence of the problem method is that a topic should be presented, whenever possible, in the form of a problem to be solved by collaboration in informal discussion between the teacher and the class. It has a sound logical basis, for the way scientific discoveries are made is that someone perceives and clarifies a problem, proceeds to collect facts and review the evidence, to form an hypothesis and to test the hypothesis by experiment. The advantages of the method is that it is one of the best ways of teaching the scientific method, it makes lessons more vital and interesting, and it ensures mental activity on the part of the class.

By no means all the science taught in schools can be presented in the form of suitable problems. Some parts of the subject must be expounded in a straightforward manner, but they should be based whenever possible on practical work and experimental demonstration. There is scope also for 'popular' treatment, for example, of the working of the internal combustion engine, the steam engine, the circulation of the blood, the coal tar industry, the electrical grid system, all of which can be illustrated by films, and the biographies of such men as Faraday and Pasteur. Here the social implications of science can be introduced, with the limitation that in the pre-School Certificate stage pupils are seldom sufficiently mature to display a deep interest.

General Science

The history of science teaching in grammar schools falls into three stages: the last thirty years of the nineteenth century when an attempt was made to teach some science, at first mainly chemistry and then also physics, for the benefit of intending university students; the first eighteen years of the present century during which, in the new municipal secondary schools, science—mainly physics and chemistry in boys' schools and botany and biology in girls' schools—was put on the same footing as other subjects, the course in boys' schools still being mainly designed as an introduction to a university course; and finally from 1918 to the present during which the conception of science for a general education has made a steady but stormy advance.

The need for widening school science courses was emphasised in a Report of a committee under the chairmanship of Sir J. J. Thomson on Natural Science in Education published in 1918. The report recommended that besides physics and chemistry some study of plant and animal life was essential, and that more attention should be devoted to the aspects of the sciences bearing on the objects and experience of everyday life.

Since that time a series of syllabuses have been put forward by the Science Masters' Association, bearing at first the title *Science for All* and then *General Science*, which included the elements of physics, chemistry and biology on a comparatively equal footing, together with some geology and astronomy.

The concept of general science is still a subject of controversy among science masters, some regarding it enthusiastically as of far greater value than a more intensive study of one or two special branches of science, and others with distrust as another term for general knowledge which fails to teach scientific principles and methods.

The general science syllabus is designed as a pre-School Certificate course. Now of 100 pupils who enter a grammar school, 83 sit for the School Certificate, 14 for the Higher School Certificate, and only 5 proceed to the university. It is clear that the old courses, which were framed almost exclusively for the benefit of those proceeding to universities and inevitably failed to achieve their true purpose unless crowned and completed by a university course, are indefensible. The neglect of biology, too, with its direct relevance to personal living such as health and diet, and to social problems, can be defended only on the grounds that the nature of its subject matter renders it more suitable for introduction after the School Certificate rather than before. This would seem to be refuted by the success of much elementary biology teaching and the postponement of its introduction in this way would mean denying it to the great majority of grammar school pupils.

Perhaps the weakest ground on which some exponents of general science take their stand is the conception of the subject as a unity in which the distinctions and cleavages between physics, chemistry and biology are obliterated. No such unification had been put forward which commands universal or even wide acceptance. The majority of school science teachers would subscribe to the following view. 'There has been some misunderstanding and ambiguity in the use of the term "General Science." Some people have thought that we advocate only a unified course of science taught by one General Science teacher and that we wish the separate science subjects of the pre-school certificate course to be replaced by "General Science." We should maintain, however, that a school is, in fact, teaching General Science if its pupils study Physics, Chemistry and Biology separately under different teachers and some Geology and Astronomy as part of their Geography. It is an increased breadth of the Science course that we advocate under the name of General Science, and we are content to leave the details of the teaching of such a course to the individual schools.' [1]

Science in the School Certificate Examination

The present position and trends in the teaching of the different branches of science up to the School Certificate examination may be seen in the following statistics.

Percentages of the total number of candidates of those taking science subjects in the School Certificates of the eight Examining Boards for the years 1936, 1939 and 1942.[2]

	1936	1939	1942
Physics	27	26	30
Chemistry	38	26	29
Physics with Chemistry	6	9	9
Biology	18	22	24
Botany	13	8	4
General Science	6	15	23

The total percentage for all science subjects in 1936 was 108 and in 1942, 119. The fact that the percentage is greater than 100 is of course due to some candidates taking more than one subject, and its increase indicates that more candidates are taking science, or that more candidates are taking more than one science subject, or both. The total numbers taking the School Certificate examination in 1936 and 1942 did not differ by as much as 1 per cent. so that the above percentages are strictly comparable.

The gains of general science seem to have been made to a considerable extent at the expense of chemistry. Physics has not only maintained but slightly improved its position, no doubt owing to its importance in the training for the various war services. Botany has almost disappeared as a subject for examination, being merged in biology and general science.

Some examining bodies, following the lead of the Northern Universities Joint Matriculation Board, are now making provision for two General Science credits, that is to say they are extending their syllabuses to give General Science the status of two science subjects. The Cambridge Local Examinations Syndicate is introducing a scheme whereby General Science can be taken either as a double or as a single subject in combination with any other science subject such as physics, chemistry or biology.

The advantage of such schemes is that they enable those who do not intend to

[1] Science in Secondary School Education : Report of a sub-committee of the S.M.A., *School Science Review*, June 1943.

[2] D. H. J. Marchant, 'Teaching of General Science in Secondary Schools,' *School Science Review*, Feb. 1944.

specialise in science to follow a minimum general science course, while the future specialist can take a more extended general science course. Alternatively the intending specialists, after a general science course in the first two or three years, can concentrate on one or two subjects, such as physics and chemistry, in the last two years before the examination.

Much has been written of the harmful effect of the School Certificate Examination on teaching in schools, and the Norwood Report advocates its gradual abolition as an external examination, and its replacement by an internal examination conducted by the individual school.

It seems likely that more harm is done by examination in such subjects as English literature than in science. Indeed, the Science Masters' Association, in their reply to an inquiry of the Norwood Committee, stated that ' an external examination syllabus provides a useful stimulus and check on teachers, pupils and syllabuses.'

The Investigators' School Certificate Report of 1932 laid down as a cardinal principle that the examination should follow the curriculum and not determine it. But they did not state who or what was to determine it. At present it is largely determined by the examining bodies. Mr. Brereton, in his book *The Case for Examinations*, stresses the mobilising and directive properties of external examinations and makes a plea for the establishment of National Subject Councils to decide what should be taught in schools. Thus the Council for Physics, he suggests, should include representatives of the secondary and public schools physics teachers, university physics teachers, the Institute of Physics, the Air Ministry and Admiralty, the Ministry of Education inspectorate and the examining bodies.

The Norwood Committee, on the other hand, would leave the fixing of syllabuses to the individual schools. While in the case of a few original teachers this might lead to valuable and interesting experiments, it is likely that there would be little change in the majority of schools, as is evidenced by the fact that so few schools take advantage of the opportunities offered by examining boards to submit their own syllabuses. Moreover the directive and progressive influence of an external examination syllabus, constantly surveyed and revised, would be lost.

Science Teaching after the School Certificate

After the School Certificate examination, specialisation in the following groups of science subjects is most common: physics, chemistry, and mathematics; physics, chemistry, and biology; botany, zoology, and chemistry; and mathematics (equivalent to two subjects) and physics. It is generally agreed that no more than two-thirds of the school time should be devoted to the specialist subjects. Thus, assuming a week of 36 periods, an average allotment of 8 periods should be given to each science subject. In some schools only lip-service is paid to this arrangement and the one-third of the time which should be devoted to non-science subjects is raided for the specialist studies. The temptation to do this is strong where candidates are prepared for four main subjects for the Higher Certificate in order to obtain exemption from the London Intermediate Examination, and also for the open scholarships of Oxford and Cambridge.

The high degree of factual information required in the Higher Certificate and university scholarship examinations has led to intense and undesirable specialisation in science in the sixth forms of schools. Both university teachers and industrialists complain that many of the boys coming to them from the schools are one-sided, they have narrow interests, and they cannot express themselves either orally or on paper.

There are two ways of breaking this rigid specialisation; one is to reduce the content of the science syllabuses in the Higher Certificate and university scholarship examinations, and the other is to demand in these two examinations other subjects such as English literature, history, and a modern language, at a subsidiary standard. Both methods are already receiving consideration by Joint Advisory Committees recently set up at Cambridge, including representatives of the University Faculties and College Scholarship Groups, the Cambridge Local and Oxford and Cambridge Examining Boards, and the Association of Women Science Teachers and the Science Masters' Association. Revised Higher Certificate syllabuses, considerably reduced in content, have been published and recommended for adoption. A most encouraging sign is that at last those responsible for the university scholarship examinations seem disposed to take a lead, since in the past their demands have nullified the arguments for lowering the standard of the Higher Certificate Examination.

At present many candidates for science scholarships at Cambridge are required to take a General Paper, but the topics set are so wide and omnifarious as to exercise little direct influence on school teaching though the indirect influence of this paper is probably considerable. A new type of test of the general education of the candidates is under consideration.

It is to be hoped that similar action will be taken in respect of the Higher Certificate Examination. The Report on Medical Education of the Planning Committee of the Royal College of Physicians of London recommends 'a broadening of the basis of the higher certificate or its equivalent, so that it includes more than a single group of subjects, classical, modern, or scientific.' Alternatively it has been suggested that every science candidate should take two compulsory papers designed to test ability in using English, capacity to translate easy passages from one foreign language, and some general acquaintance with social, historical and cultural ideas.

On the arts side the specialisation is equally biassed since very few classical or modern sixth forms include science in their curriculum. Here the need is for a course on the history, methods, and social effects of science similar to the one already outlined. Its widespread adoption in the schools can be ensured only by the introduction of a compulsory paper in the Higher Certificate and university scholarship examinations.

It is true that there is a danger of removing much of the inspirational and cultural value from a subject, particularly one designed to broaden outlook and orientate the mind, by making it an examination subject; but it is surely better to take this risk rather than acquiesce in the almost complete neglect of the humanities by the scientists and of science by the humanists.

Technical High Schools

The technical high schools, proposed in the Spens Report of 1939 and now to be provided under the Education Act of 1944, are a development of the junior technical schools. The latter give an education directed mainly towards the engineering and building industries, with science and its application to those industries as its central core. Their pupils number at present less than 30,000 as compared with over 500,000 at the grammar schools.

The age of entry to the junior technical schools has been 13+ and they have provided a two- or three-year course. Since the grammar schools recruit at 11+, they have removed all the abler children from the primary schools before the junior technical schools could make their selection. In the words of the Spens Report, 'This tends inevitably to create a disproportion in the distribution of brain power as between what may be broadly termed the professional and industrial worlds.' Accordingly the age of entry to the new technical high schools is to be 11+ (with a leaving age of 16). In order to facilitate transfers between them and the modern and grammar schools at the age of 13+, the curricula of the three types of secondary schools are to be similar for the first two years.

One of the most criticised recommendations of the Spens Report was that the technical high schools should be housed in technical colleges, whose accommodation is used mainly at night and is vacant during the day. The amenities and atmosphere of the often unlovely buildings of the technical colleges is unsuitable for small boys, and, while there are strong grounds for a close liaison between technical colleges and technical high schools, separate buildings for the latter should be provided. It is probable that many new schools will be built and that some existing grammar and modern schools will be converted. In London, multilateral schools are proposed embodying all three types of secondary school in one institution, not so much with the object of educational efficiency as to facilitate equality of esteem.

The curriculum of the technical high schools will have science as its core, but the science will differ from that taught in the grammar schools by having a practical and vocational bias. About one-third of the time will be devoted to science, one-third to workshop training and engineering drawing, and one-third to English and aesthetic subjects.

The liberal and disciplinary value of science teaching need be in no way impaired by giving it a vocational bias so long as broad principles and the wider aspects of the subject are not neglected. The value to industry of a large body of recruits with a thorough scientific training can hardly be overestimated. Britain during the present century, although second to none as a pioneer in pure science, has perhaps fallen behind in technical invention. The fundamental remedy would seem to be provided by the technical high schools, so long as their social status is such as to enable them to secure their fair share of the abler boys.

Modern Schools

Modern schools are intended for the remaining children, between the ages of 11+ and 15, when the intellectual cream, of between one-fifth and one-quarter of the annual output of the primary schools, has been removed to the grammar schools, and a smaller proportion to the technical high schools.

In 1939, with the school leaving age at 14, accommodation in separate senior departments, in senior and central schools (now to be termed modern schools), was sufficient

only for 50 per cent. of the children. The raising of the school leaving age to 15 and eventually to 16, will increase the task of providing accommodation and necessitate the building of many new schools. It opens up a new educational field in this country and will call for experiment and a fresh tradition.

Experience in senior schools suggests that the discipline of a formal study of physics, chemistry, and biology, whether as separate subjects or as general science, is unsuitable, and there is general agreement that too much stress on the teaching of the scientific method is misdirected effort. What is required is a series of projects or topics, cutting right across the usual divisions of the sciences, which are practical rather than academic, concrete and utilitarian rather than abstract and theoretical.

The curriculum of the modern schools will include considerable manual training and handicrafts such as woodwork, metalwork, gardening and cookery. This can be correlated with some of the science teaching, as, for example, in the making of models and scientific apparatus in the workshop. There is a strong body of opinion which advocates far more handwork in the grammar schools, partly for the value and pleasure of manual skill and partly on the grounds of its function in intellectual development. But in the modern schools the main bias will be towards manual training.

The aim of the science teaching in the modern schools should be to give an explanation of the scientific environment, a knowledge of hygiene and how the body works, and some idea of what science has achieved. Obvious topics are, the human body and its care, how animals and plants live, how man utilises natural materials from the earth's crust, and machines. The curriculum could be given a bias in accordance with the local industry—coal, iron, cotton, agriculture and so on.

Existing schools are poorly equipped with laboratories and apparatus. There is here an urgent need for improvement since science teaching, even of this wide and practical nature, if it is to be worthy of the name, must be based on experimental demonstration. The use of films, broadcast talks, visits to museums and factories, all help to give variety and interest to the teaching.

Many experiments on teaching science by the topic method have been made in the American high schools which educate a large proportion of American youth, including a majority of intellectually mediocre but nevertheless keen and energetic youngsters. When drawing up sciences syllabuses the Americans have explored the possibilities of relating every item to a need of the student as individual and citizen—for example, health, self-assurance, faith in intelligence in solving social problems, cheerfully shouldering a share of home duties and so on. But the method does not seem very fruitful in deciding what parts of science to teach, although valuable in planning the activities and way of life of the school as a whole.

It is to be hoped that the modern schools will emulate the vitality and readiness to experiment of the American high schools. The following, for example, is part of a course of physics and chemistry which, although designed for the 11th grade, age about 16+, might be modified for the last year in a modern school.[1]

The work was done by the class as a committee, with the teacher as technical adviser. The syllabus was divided into units of which unit (1) was Household Machines and Appliances. One group of three expressed interest in the piano, and were given an old one to take apart. They were given a list of questions to answer—why are the strings of varying thickness? what is concert pitch? and so on. They made several visits to the local music shop; American firms seem very patient in the cause of education. Eventually they passed on their findings to the rest of the class in the form of a lecture illustrated by lantern slides, models they had made to show the working parts of a piano, and a sonometer to demonstrate the phenomena of vibrating strings.

Another group dissected an old car, obtained from a wrecker's yard, and each group when it had finished its investigations lectured to the rest.

Until classes have been reduced to a smaller size such methods will be impossible in our modern schools. But they do teach the child how to search for information, they relate scientific knowledge to everyday life, and though the actual knowledge gained may be superficial a high standard of scholarship cannot be expected.

Conclusion

The place of science in a liberal and general education only has been considered in this pamphlet. Nothing, for example, has been said of technical colleges. The importance of what has been omitted is, of course, evidenced by the fact that the modern world cannot function without a supply of technicians.

Much more space has been devoted to the grammar schools than to the other types of secondary schools. This is natural since the

[1] *Science in General Education.* Progressive Education Association of America, Appleton Century, 1938.

grammar schools and public schools at present are educating nearly all those who pass into the universities and because the modern schools and technical high schools have yet to establish their traditions. The function of science teaching in the grammar schools, it has been maintained, is to provide a training in scientific method and to lay down a basis of elementary scientific knowledge for further education.

It is in the further education, at a more mature stage, whether in the sixth forms of grammar schools, at the university or in adult education, that there seems the greatest prospect of immediate progress. Only during the past twenty years or so has the historical, philosophical and sociological aspect of science come to the fore, and its importance in education been realised. It is easy for those engaged in science teaching to be so immersed in one or more specialised branches of science as to be unable to see the wood for the trees. There is an endeavour now, on the part of some schoolmasters and university teachers, to make a detached and critical survey of science, to assess its impact on society, and to place it in relation to other activities such as art and religion. Such a presentation of science should play an indispensable part in education, whether emphasis is laid on the sociological function of education or on its inculcation of values.

PRODUCING OILS: SCIENCE LENDS A HAND

By Dr. G. D. Hobson

Oil is a term variously employed to cover a wide range of substances. It includes the fluid fixed or fatty oils, soft fats which may be fluid in the country of origin, hard fats and still harder waxes, odoriferous oils, all obtained from animal or vegetable sources, and mineral oils, solid or liquid, which occur naturally or are produced in the destructive distillation of oil shale, coal or carbonaceous matter.

Oils are composed of organic compounds, compounds in which carbon and hydrogen are the main, and in many cases the only, elements. Oils are immiscible with water, and are combustible. Many of them are greasy fluids at ordinary temperatures or at temperatures below 100° C.

The broad chemical distinction between animal and vegetable oils on the one hand, and mineral oils on the other, is that the former consist mainly of fatty acid esters, and therefore contain the element oxygen in addition to carbon and hydrogen, while the latter are largely composed of hydrocarbons, compounds containing hydrogen and carbon only. It may be noted, however, that some animals and vegetables form small amounts of hydrocarbons, and some mineral oils contain oxygen-bearing compounds.

The fixed (non-volatile) oils and fats are esters formed by the interaction of one molecule of the tri-hydric alcohol glycerol with three molecules of fatty acid, whereas the animal and vegetable waxes are generally formed by the interaction of one molecule of fatty acid with one molecule of a mono-hydric alcohol, and rarely of two molecules of fatty acid with one molecule of a di-hydric alcohol.

The essential (volatile) oils differ chemically from the fixed oils and fats. A considerable number of different types of organic compounds are known to occur in them. In addition to hydrocarbons, which may be present in considerable amounts, there are compounds which contain oxygen, sulphur or nitrogen, in addition to carbon and hydrogen.

No natural fat or oil consists of a single chemical compound.

Table I

Examples of oils, fats and waxes

Animal	Vegetable	Mineral
Oils	*Oils*	*Natural oils*
Cod-liver	Linseed	Petroleum
Whale	Rape	
Neat's-foot	Olive	*Derived oils*
Fats	*Fats*	Oils obtained by the distillation of oil shale, coal or other carbonaceous matter.
Lard	Cacao butter	
Tallow	Palm kernel	
Butter	Coconut	
Waxes	*Waxes*	*Synthetic oils*
Beeswax	Carnauba	Variously produced.
Woolwax	Sugar cane	
	Essential oils	
	Turpentine	
	Eucalyptus	
	Rose oil	

Table II

World production of oils in 1938.

Animal fats and oils . .	2,835,000 tons *
Vegetable fats and oils .	5,214,000 tons
	Total 8,049,000 tons
Crude petroleum . .	269,000,000 tons
Gasoline from natural gas .	8,660,000 tons
	Total 277,660,000 tons
Petroleum substitutes :	
From coal . . .	3,900,000 tons **
From oil shale . .	338,000 tons **
Alcohol for motor fuel .	978,000 tons **
	Total 5,216,000 tons

* This estimate is likely to be low because of small scale production in many countries.

** These figures are estimates, and in the case of oil produced from coal, and possibly oil from oil shale also, they are now likely to have been substantially exceeded.

Animal and Vegetable Oils and Fats

Fixed Oils and Fats

Animal fats are enclosed mainly in the cellular tissues of the intestines and back. Some waxes are secreted by insects, and wax occurs on sheep wool. A few liquid waxes are known, including those found in the blubber and head cavity of sperm whales, and those stored in the stomachs of certain polar birds. The fat of flesh-eating animals seems to be produced chiefly from fats taken as food, but it can be derived from carbohydrates, and these are probably the source in herbivorous animals.

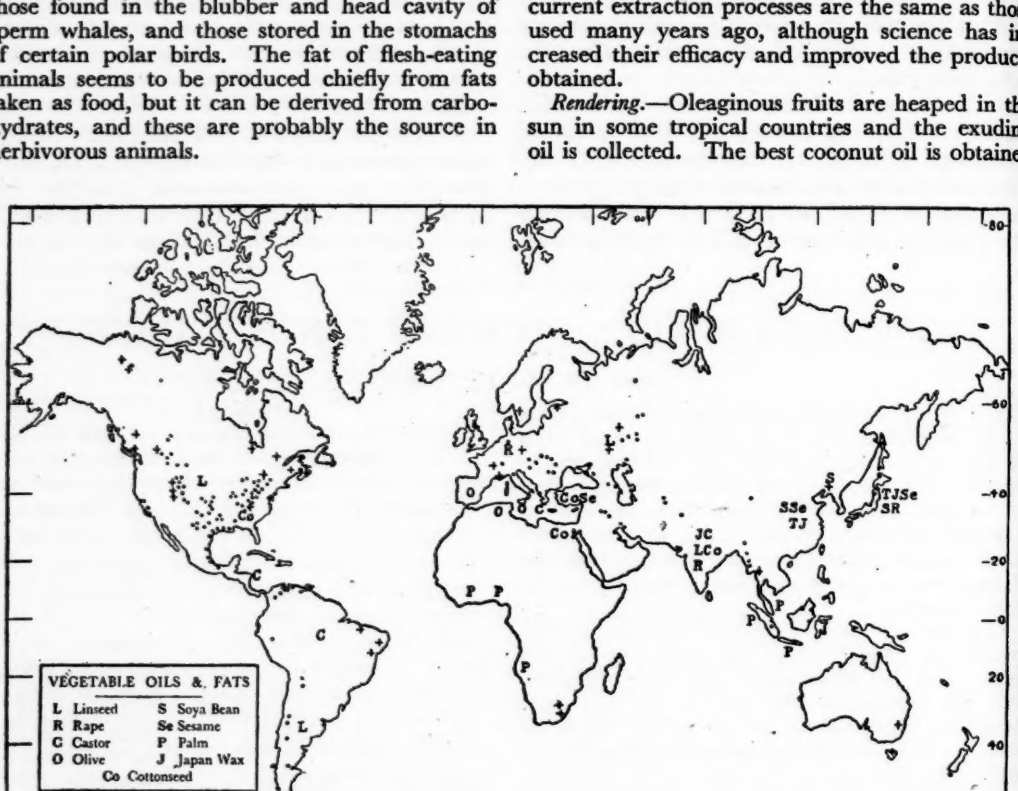


Fig. 1.

Dots show oil fields and oil-field areas diagrammatically. Each dot represents one or more oil fields, since the scale is too small to be more precise.

Crosses show some of the areas with oil shales and allied deposits. Only a few of these deposits are exploited at present.

Letters indicate broadly the areas in which some of the more important vegetable oils and fats are produced.

Vegetable oils occur almost exclusively in seeds and fruits ; vegetable waxes usually appear as thin films covering leaves and fruits. Carbohydrates are probably the immediate source of oils and fats in plants, and in the case of seeds and fruits the formation of oils and fats takes place late in the ripening process. In the unripe condition sugars and starches are present in the seeds and fruits, but no fatty acids or oils. During the ripening process it is probable that these carbohydrates are broken up and converted to fatty acids and oils.

Science, through plant breeding and selection, has succeeded in developing oleaginous plants which yield more oil, can be grown under different climatic or soil conditions, and are more suitable for harvesting and treatment, or more resistant to disease than the wild varieties. In at least one instance artificial pollination has been used with beneficial results on oil production, provided that due attention is given to manuring and other factors.

Recovery of Oils and Fats

The oil and fat industry is as old as the human race, and the principles underlying some of the current extraction processes are the same as those used many years ago, although science has increased their efficacy and improved the products obtained.

Rendering.—Oleaginous fruits are heaped in the sun in some tropical countries and the exuding oil is collected. The best coconut oil is obtained by boiling fresh kernels in water. A similar method is used for recovering animal fats, the fat-bearing tissue being cut up and heated in water at atmospheric or some higher pressure. The fat collects on the surface of the water and is strained or filtered off, while the membranous matter sinks and is later pressed to extrude any enmeshed fat.

Pressing.—Boiling cannot be applied to small seeds such as linseed and rape seed. Such seeds are therefore cleaned, the husk is removed, and the kernel is ground to a meal which is subsequently pressed. In cold pressing the expressed oil dissolves less colouring matter than in hot pressing, thus giving high-quality edible oils. Pressing at high temperatures gives a greater oil yield than cold pressing, but the oil is harsher, more coloured and less suitable for food.

Solvent extraction.—Hot or cold volatile solvents

may be used for extracting oils from seeds ground less finely than for pressing. In cold extraction the solvent is allowed to percolate through the meal using the counter-current principle in which fresh solvent percolates through meal from which much of the oil has been extracted, and solvent with much oil in solution percolates through meal from which little or no oil has been extracted. In hot extraction the solvent is vaporised, condensed and brought into contact with the meal. It extracts oil, and the solution is automatically siphoned back into the vessel from which the solvent was originally vaporised. The solvent is re-vaporised, and the cycle of events is continuous.

The oil-containing solution obtained by hot or cold extraction is heated to evaporate the solvent, which is recovered for re-use. In a good process the solvent losses do not exceed 1 per cent. The oils and fats left on evaporating the solvent are generally of high quality.

The oils and fats obtained by any of the above processes usually require improvement, but their variability causes each one to constitute a special problem. The general methods of improvement employed include filtration through adsorbents such as fuller's earth or charcoal. Free fatty acids are removed from edible oils by treatment with alkalies or alkaline earths.

In many fixed fats and oils the compounds are such that the number of hydrogen and oxygen atoms in the molecules is not the maximum which could be combined with the carbon atoms present. These oils and fats are said to be unsaturated. The degree of unsaturation varies in different types of oil, and in the so-called drying oils it is high. In the semi-drying oils the degree of unsaturation is less. The drying oils and fats readily absorb oxygen from the atmosphere, and when in thin layers quickly form a tenacious skin or film, a property which makes them suitable for use in paints and varnishes. The semi-drying oils take up oxygen much more slowly and merely thicken ; they are unsuitable for paints and varnishes. Oils like olive oil are non-drying and do not oxidise in the above manner.

Hydrogenation

When hydrogen is passed through a heated oil of the unsaturated type in the presence of a finely-divided catalyst (commonly nickel), the hydrogen enters the molecules making them more saturated. This process of hydrogenation hardens the oils, and if carried far enough deodorises them also. The deodorising makes practicable the use of hydrogenated whale oil in margarine, cooking fats, salad oil and hard soap, and hydrogenated fish oil in hard soap. The degree of hardening can be controlled. Hardened fats are valuable industrially, for cheap vegetable oils hardened to the correct consistency can frequently be used instead of the dearer tallow and lard.

The process of hydrogenation was conceived and rendered practicable by scientific research.

Uses

Animal oils are employed for leather-currying, burning, lubrication, medicinal purposes, soap- and margarine-making, and the steel plate industry. Animal fats are used in food, soap- and candle-making, perfumery and pharmacy.

Linseed, tung, and to a less extent other drying oils, are used as a basis for paints, varnishes and linoleum, and in making soft soap. The semi-drying oils are variously employed in burning, lubrication and in food- and soap-making. Non-drying oils find uses in food, soap-making, lubrication, perfumery, pharmacy and medicine. The vegetable fats are used for food, in soap- and candle-making, tin-plating, polishes, pharmacy and perfumery.

Use is made of animal and vegetable waxes in polishes, candle-making, lubrication, pharmacy, and making gramophone records.

Essential Oils

The essential oils occur in different parts of plants : mainly in the petals in scented flowers such as the rose ; in the leaves and bark in spice-producing plants ; throughout the plants in other cases. Many of them are recovered by a distillation process which involves the vaporisation of the oil from the oil-bearing part of the plant in steam, the steam and oil being subsequently condensed and separated. In other instances solvent extraction or pressing is employed.

Essential oils are used for perfumes, for flavouring, in medicine. Turpentine is used in paints and varnishes.

Petroleum

Petroleum in its liquid, solid and gaseous forms has long been known. The earliest records of its use refer to the employment of bitumen, one of the solid forms, before 3000 B.C. However, the petroleum industry is considered usually to date from the drilling of the Drake well at Titusville, Pennsylvania, in 1859. Before that date petroleum had been obtained from pits, surface deposits and seepages, and at times from accidental incursions into mine-workings and brine- and water-wells. In these early times the different forms of petroleum were variously used for paving, cementing, lubrication, illumination and medicinal purposes.

When systematic petroleum production began in 1859 the chief product sought was kerosene for lamps, since the supply of whale oil was proving inadequate, and the existing substitute obtained by retorting coal or oil shale was not particularly satisfactory. In preparing kerosene from petroleum considerable amounts of other products were obtained, and it became necessary to find uses for these. The heavy residue was used as a furnace oil or was partly converted into lubricants to augment or replace lubricants obtained from animal and vegetable sources. At first only small outlets could be found for gasoline, for the first automobile driven by a petrol engine and incorporating many of the essential features of the modern car did not appear until 1894. Some years after the beginning of the present century when the motor car began to be more than a curiosity, gasoline ceased to be a drug on the market, and from that time onwards became the primary product. Soon methods of increasing the proportion of gasoline obtained from a crude petroleum were introduced.

TABLE III

Year	Approximate percentages of main products obtained from crude petroleum			
	1904	1914	1924	1938
	Per cent.	Per cent.	Per cent.	Per Cent.
Gasoline	10	17	32	44
Kerosene	48	26	10	6
Lubricants	12	7	5	3
Gas oil and fuel oil	14	46	49	38
Miscellaneous	16	4	4	9

TABLE IV

Type of gasoline	Relative amounts of different types of gasoline produced in different years		
	1918	1928	1938
Straight-run	1·00	1·00	1·00
Cracked	0·17	0·59	1·08
Natural gasoline	0·10	0·19	0·20

Nature of Petroleum

While hydrocarbons are the principal compounds present in petroleum, there are also compounds which contain relatively small proportions of oxygen, sulphur or nitrogen in addition to carbon and hydrogen. Traces of a wide variety of metallic elements are found in petroleum, but their actual mode of occurrence is rather uncertain. The gaseous representatives of petroleum comprise only a small number of hydrocarbons, all of the same type, but the liquid and solid representatives vary widely, not only in the proportions of the different hydrocarbons and other compounds present but also in the nature of the compounds.

Nature of an Oil Pool

Crude oil and natural gas are the forms of petroleum most extensively exploited.

An oil pool is an accumulation of petroleum from which the oil can be recovered without having to excavate and treat the rock in which it occurs. The oil is found chiefly in the pores of relatively coarse-grained rocks. The pores are irregular in shape and extensively inter-connected. A measure of their sizes in many reservoir rocks may be gained from the fact that the diameters of spheres which will just fit into their widest parts commonly range 0·005 in. to 0·0007 in. Sometimes there are also some rather larger oil-filled openings in the rocks, such as fissures from a fraction of an inch to several inches in width, and other comparatively large cavities.

The rock containing the oil is known as the reservoir rock. Above it is a sealing rock layer, the cap-rock, which has much finer pores, and when not fractured or unduly thin this prevents the upward escape of oil or gas from the reservoir rock. The lateral and basal confinement of the oil also may be provided by an increase in the fineness of the rock pores, or by salt-water filling the pores of the lower parts of the reservoir rock.

Commonly the reservoir rock is inclined or arched. In the higher parts gas alone may be found, and salt water in the lower parts, with oil in the intermediate zone, an arrangement which conforms with the densities of these three substances. The oil usually has much gas in solution. Moderate amounts of salt water may be present in the pores in the oil or gas zones, without being recovered in the ordinary exploitation of the oil or gas.

Reservoir rocks are often sands, sandstones or limestones, while cap-rocks are usually clays or shales.

The oil and gas are usually under considerable pressure, the magnitude of the pressure generally increasing with the depth of the reservoir rock, and commonly being of the same order as that which would be provided by a column of water extending from the surface down to the reservoir rock. This pressure is used as far as possible to bring the oil to the surface in wells, but when it is insufficient for the purpose other means are used.

Oil production has been obtained from reservoir rocks occurring at depths from the surface down to more than 13,000 ft., and is already being sought by wells over 15,000 ft. deep. In some oil fields there are a number of reservoir rocks, one below another. The thickness of individual reservoir rocks ranges from a few to hundreds of feet. The area of oil-charged reservoir rock varies widely from field to field, one of the largest known oil fields, East Texas, covering more than 200 sq. miles. From its discovery in 1930 to the end of 1942 East Texas had produced 1,821,593,900 barrels of oil from more than 25,000 wells. Estimates of its recoverable reserves range up to 3,500,000,000 barrels of oil.[1]

Oil accumulations are relatively common, but those which are commercially valuable are much less common. The minimum size of a commercially valuable oil accumulation depends on its depth, nature and geographical position, on the quality of the oil, general economic and political conditions, and the state of technical development.

Bitumen often occurs like oil and gas in the pores of a rock, but it also occurs as vein-infillings, sometimes of considerable size.

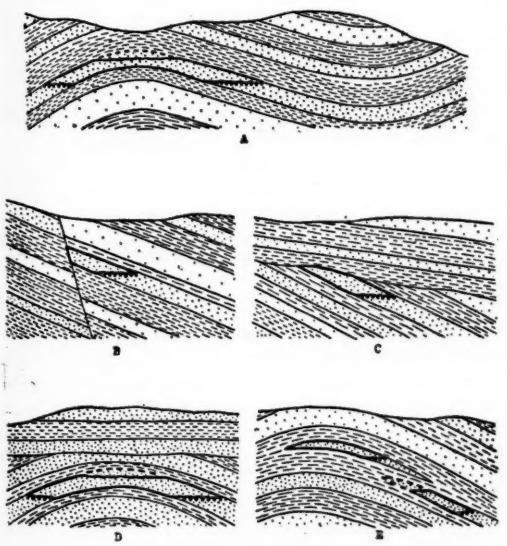
Formation of Petroleum and of Oil Pools

Oil is generally found in reservoir rocks of sedimentary origin, and even when the reservoir rock is an igneous rock it is always closely associated with sedimentary rocks. Sedimentary rocks are formed from mineral fragments and dissolved matter produced by the action of the weather and other agencies on rocks exposed on the land surface. The mineral fragments and dissolved matter eventually reach the sea or a lake where they are deposited as part of a sedimentary rock in process of formation.

The waters in which sedimentary rocks are formed often abound in living organisms, both

[1] One barrel = 42 U.S. gallons or approximately 5·6 cubic feet.

animal and vegetable, ranging from microscopic forms upwards. Under certain conditions on death these organisms may be deposited along with the mineral matter. In the newly-deposited coarser-grained sedimentary rocks, such as sands and sandstones, which are formed in the shallower and more agitated waters, bacteria live which, unless the rate of accumulation of mineral and organic matter is extremely rapid, succeed in consuming the organic matter, thus preventing its persistence in the sediments. However, in the finer-grained deposits, the clays, shales and limestones, which are laid down in rather deeper and stiller waters, the bacteria are of different types,



Coarse-grained rocks with relatively large pores and other openings, e.g. sands, sandstones and some limestones.

Fine-grained rocks with much smaller pores, e.g. clays and shales. These form good cap-rocks.

Top of gas-bearing zone in reservoir rock.

Boundary of the zone in the reservoir rock containing oil with dissolved gas, in pores and other openings.

Top of salt-water-bearing zone in reservoir rock.

Simplified vertical cross-sections of the upper part of the earth's crust, showing several different types of oil accumulation.

because these waters are frequently deficient in dissolved oxygen. Under such conditions the organic matter may not be completely destroyed, but may be preserved in a modified form. Thus there may arise the foetid conditions which are characteristic of deposits containing organic matter, and formed under stagnant waters. The modified organic matter contains less oxygen, nitrogen and sulphur than the original organic matter, and so more nearly approaches petroleum in its bulk composition, since organic matter is largely composed of compounds of carbon and hydrogen, together with the above elements.

The subsequent stages in the transformation of organic matter into petroleum are more conjectural. Some believe that they are effected mainly by bacteria, with the consequent implications that petroleum must be formed relatively soon, from the geological point of view, after the formation of the sediments, and at temperatures not very different from atmospheric. Efforts to discover newly-formed petroleum in recently deposited sediments have so far given only a little indirect support to this hypothesis, but the technique employed has not been such as can be considered to constitute a satisfactory test. It may be noted, however, that the formation of methane, the chief constituent of natural gas, is frequently observed in deposits containing organic matter.

Others believe that the final transformation from the modified organic matter to petroleum takes place through the agencies of high pressures and relatively high temperatures, which are attained by deep burial of the sediments. The over-all rate of accumulation of sediments, and hence the rate of increase of depth of burial, is extremely low. This feature, coupled with the fact that the rise of temperature with depth is roughly 1° C. per 55–125 ft., means that the formation of petroleum in the above manner cannot take place until the organic matter has been both long and deeply buried.

Radio-activity has been suggested as playing a part in the conversion of organic matter to petroleum.

It will have been noted that although the reservoir rock from which oil is extracted commercially is generally one of the coarser-grained types of rock, it is suggested above that petroleum is formed in the finer-grained types of rock. If this is so there must be a stage at which oil is transferred from the latter to the former.

When laid down, the finer-grained rocks are in a condition in which their constituent grains are not so closely packed as they can be. In this uncompacted state they have a large proportion of pore space which is occupied by fluid. As they become more deeply buried these deposits are squeezed by the weight of the sediments overlying them, and some of their fluid is forced out. On the other hand, the coarser-grained rocks are deposited essentially in their state of closest packing, and so they undergo little change in porosity on burial.

The fluid squeezed from the finer-grained rocks on compaction generally moves in an upward direction. However, if it encounters a layer of coarser-grained rock—as it may well do, for great thicknesses of wholly fine-grained or wholly coarse-grained rocks are unusual—it may deviate considerably from a directly upward path, if thereby the total resistance to movement along its entire path will be less than that for any more direct path. The fluid from the finer-grained rock may contain some oil and gas in addition to water if that rock has been a site of petroleum generation. This oil and gas will be filtered out and retained in the coarser rock until that is filled to its maximum capacity with oil and gas. In this way the oil and gas reach the reservoir rock. Incidentally, this process, if the correct explanation, gives a bias towards a belief in the formation of petroleum comparatively soon after the deposition of the organic matter, for then compaction will be most active.

Within the reservoir rock the arrangement of gas, oil and water according to their densities

takes place to a degree which depends on the inclination of the rock and its coarseness.

Discovery of Oil Pools

An oil pool has a geological setting, and the basic views on the mode of origin of an oil pool are a product of geological speculation, although the working out of the details of the transformation of organic matter to petroleum requires the co-operation of the chemist, biochemist and geologist. Consequently, the discovery of an oil pool must be essentially a matter for the geologist until commercially valuable oil accumulations can be discovered directly with certainty, and even then geologists will play an important part in indicating the most favourable areas for search and in the development of the discoveries.

Oil or gas seepages—escapes of oil or gas to the surface of the earth by exposure of the reservoir rock or by way of a fracture in the earth's crust leading to the reservoir rock—have drawn attention to many areas in which oil pools have been found. Oil fields have then been developed either by the application of geological principles in the selection of the most favourable spots for drilling wells, or by more or less random drilling.

The higher parts of the reservoir rock are more likely to contain oil than the lower parts, and therefore it is a matter of prime importance to determine the form of the reservoir rock in order to locate the wells successfully, once the presence of oil source and reservoir rocks seems probable from geological studies. Provided that the rock layers exposed at the surface are simply related to those at depth as regards their structural form, purely geological methods are generally capable of deciding on the most suitable points at which to drill in order to test the reservoir rock for the presence of oil and gas. But when this condition does not obtain, or when the surface evidence is poor or the arching of the rock layers so gentle that reliable predictions from surface data are not practicable, other assistance must be sought. Relatively shallow holes may be drilled to obtain additional geological information, or geophysical methods of exploration may be employed, but the effective and economical use of either of these methods is most certain when guided by sound geological advice. In the case of geophysical exploration the observational data are frequently capable of several interpretations, not all of which are equally probable geologically.

The type of geophysical method which can be most effective depends on the nature of the problem. Some methods are used for broad reconnaissance while others are employed for local detail. In the magnetic method observations with a delicate magnetic needle indicate anomalies in the earth's magnetic field due to the presence within the earth's crust of rocks of different magnetic properties. Similarly, under suitable conditions the gravitational method detects the existence of rocks of different densities, and operates by measuring the variation in the gravitational pull on part of an instrument when the instrument is moved from point to point. In seismic methods explosive charges are detonated to send impulses into the earth's crust, and these impulses (miniature earthquake waves) are picked up by instruments (seismometers) placed at different distances from the explosive charge. From measurements of the time which elapses between the firing of the shot and the arrival of the impulses at the seismometers, and the rates at which the impulses travel in the different types of rock through which they pass, deductions may be drawn in many instances about the form and depth of certain rock layers.

With the possible exception of geochemical methods, which have yet to be accepted generally, there is no direct method other than drilling a well of ascertaining whether an oil accumulation exists at depth, and even a well may not be a conclusive test if it is badly located or insufficiently deep. Geological and geophysical methods indicate the most likely area for drilling, from a structural point of view, assuming that oil has been formed in the region, and that it has accumulated in some reservoir rock from which it can be recovered in adequate quantities and at suitable rates by the existing methods of production.

Over the years there has been a change in the measure of success attained by the various methods of locating oil pools. In the early days most pools were discovered by obvious surface evidences. Then followed a period during which purely geological investigations provided the bulk of the discoveries, and that has been succeeded by a phase in which the employment of geophysics has contributed markedly to the successes. Throughout, exploratory wells drilled casually or at random have provided discoveries, many of considerable magnitude, and the technique of subsurface geological studies by means of data provided by wells has contributed steadily towards the discovery of new fields.

There is a risk that an exploratory or wildcat well will fail to find oil. Such a well has been defined as a well located a comparatively considerable distance outside the limits of a producing or producible oil pool, as those limits are known at the time of its drilling. An analysis of wildcat drilling, as so defined, in U.S.A. during the years 1937 to 1943, inclusive, shows that on an average wildcats drilled at locations selected by geological and geophysical studies are four times more likely to succeed than those drilled at locations chosen without scientific advice. Even with scientific advice there are, roughly, five failures for each success.

Drilling

The drilling of an oil well is a feat of engineering which must be carefully watched from the geological point of view if the well is to be both a mechanical success and a source of data which will aid in future oil development in the area.

There are two methods of drilling. In the cable-tool method a hole is pounded in the rock by a tool which is lifted on the end of a cable about thirty times a minute and allowed to fall so as just to strike to rock at the bottom of the hole. The rock cuttings are removed from time to time, after withdrawing the tool from the hole, by lowering a bailer to the bottom. This method is not considered suitable for drilling deep wells, and is not widely used for greater depths than about 4,000 ft.

In the rotary method a cutting bit on the lower

end of a column of hollow pipe is rotated in the hole at speeds up to 250 r.p.m., and over, by turning the top end of the pipe which protrudes from the hole. The cuttings are removed by pumping mud down the hollow pipe, out through holes in the bit, and back to the surface through the annular space between the outside of the pipe and the walls of the hole. The mud runs into a pit where the cuttings fall to the bottom, or through vibrating screens which remove the cuttings, and then returns to the well. It is continuously circulated during drilling. Ideally, the mud serves a number of other purposes, such as supporting the well walls, controlling the entry of water, oil or gas into the well, and preventing cuttings settling round the bit and drill-pipe should drilling and mud circulation have to be stopped without withdrawing the bit from the hole.

Near the surface the hole may be over 20 ins. in diameter, but a narrower hole is drilled at depth, and in deep wells the diameter may only be about 6 ins.

Both methods of drilling require a tall derrick, generally over 100 ft. high, together with hoisting gear, in order to handle the tools, drill-pipe and casing. In addition, machinery is necessary for rotating the drill-pipe or working the cable-tools, and pumps for circulating the mud. Power is supplied by a steam engine, internal combustion engine or electric motor.

The holes are lined with steel casing in order to support the walls, and, where necessary, to permit the cementing off of water-bearing strata, water from which might damage the oil-producing formation, or to shut off oil- and gas-bearing formations from which production is not required. The casing is usually inserted at intervals during the progress of casing, the wide casing extending only to relatively small depths, and narrower casing passing through this to greater depths.

In addition to the skill shown in the design of machinery and equipment for drilling wells, the present drilling achievements depend on metallurgical advances and on the chemist's and physical chemist's success in dealing with problems connected with drilling muds and cements. Exceptionally hard alloys are needed for drilling bits, and special steels are necessary for the drill-pipe. The emplacement of cement in a well at a point where the temperature may be considerably above atmospheric calls for cements in which the onset of the initial set has been retarded by the addition of certain chemicals.

At times the drilling mud used in a well accounts for an important proportion of the total costs. Extensive investigations have been made to find ways of obtaining the desired properties in muds. Chemicals, highly colloidal clays, and finely-ground dense minerals such as barytes may be added to adjust the fluid and colloidal properties, the density, and the facility with which water from the mud enters or affects the formations penetrated by the well.

During the drilling a careful watch is kept on the cuttings made, and cores may be cut and recovered for examination. Such examination shows the type of rock being drilled and may reveal the nature of the fluids in the rock pores, whether gas, oil or water. The returning drilling mud is watched for signs of oil and gas when the well is approaching rock layers which may contain oil and gas. Physical measurements made on the rock cores show whether the rock is likely to permit fluid flow through it at rates which will give good oil wells. Examination of the rock cuttings often makes possible the correlation of geologically similar beds from well to well, and may provide fossil evidence concerning the age of the rocks.

In recent years the examination of rock specimens recovered from wells has been supplemented by lowering instruments down the wells ; these instruments allow the continuous recording at the surface of certain electrical and radio-activity measurements on the beds through which the instruments are passing. The measurements are recorded, while the instruments are being lowered, as continuous curves which have characteristic forms, and can often be used to infer the type of the rock, the nature of its fluid content, its permeability and porosity. The electrical measurements must be made in uncased sections of the hole, but the radio-activity measurements can be made through casing, if necessary. Radio-activity measurements are now employed to indicate possible oil-bearing horizons which have been missed and cased off in old wells.

Normally, the aim is to drill wells which do not depart markedly from verticality, but at times wells are drilled which are intentionally not vertical at depth in order to gain access to points which cannot be so conveniently reached by vertical wells.

The average cost of a well is about £5,000, but some cost more than £50,000. Exploratory wells tend to be far more costly than ordinary development wells.

The average depth of the wells completed in U.S.A. during the first half of 1944 was 3,327 ft.

Production of Oil from a Well

When the well has entered the oil-bearing formation from which it is intended to produce oil, casing with a perforated section is set opposite this formation. Generally a narrower tube is placed inside the casing in order to promote more efficient conditions of flow. Valves and other fittings are erected at the surface for purposes of control.

The completion of a high-pressure well is a highly skilled operation, for if the well gets out of control serious damage and loss of oil and gas may result.

In hard reservoir rocks which are not very permeable the flow of oil and gas may be stimulated by detonating explosive charges in the bottom of the well to fracture the rock. In limestone reservoir rocks an alternative method of stimulation is to introduce hydrochloric acid with the object of widening the joints and fissures near the well by dissolving some of the rock.

When it is desired to produce oil from a formation which has been cased off by blank casing, perforations can be made by firing bullets from a specially designed gun lowered to the appropriate point in the well.

In a naturally flowing well, oil highly charged with gas bubbles enters the casing through the perforations, and as this mixture rises in the well the gas bubbles expand. The mixture thins first to a froth, then, when the bubbles break, to a spray

of gas and oil. This spray passes out of the top of the well and on to a separator where the gas, oil, and any entrained water and sand are separated.

After a period of instability the oil output of a well declines, relatively in some types of oil field, and more slowly in other types. Wells are abandoned when the rate of production becomes unprofitably low. The ratio of gas to oil produced increases with the age of the well, but this increase can be controlled to some extent by suitable adjustments.

When a well ceases to flow naturally artificial lifting methods must be applied. These methods include mechanical pumping, and gas-lift, a method in which gas is pumped down the open ring between the casing and tubing. This gas supplements the gas associated with the oil and creates conditions such as are described above for a naturally flowing well.

Three mechanisms in addition to gravitational drainage are involved in driving oil to a well. These are active in varying degrees in different fields, and at times to different extents at successive stages in a single field's producing life. In some fields it is possible by varying the rate of production to cause one or other mechanism to dominate the production process.

(*a*) *Dissolved-gas drive.*—When a well penetrates an oil-bearing formation and reduces the pressure on the oil, the dissolved gas begins to come out of solution, and its expansion drives oil and gas into the well. This is a mechanism which must operate in some measure so long as the oil has any dissolved gas, unless water-drive maintains a higher pressure than the gas saturation pressure.

(*b*) *Gas drive.*—If free gas overlying the oil is allowed to expand it will act to some extent like a piston, forcing oil into the well, provided that the gas cannot enter the well directly.

(*c*) *Water drive.*—The third mechanism is one in which the continuation of the reservoir rock is extensive and charged with water which can move, and, piston-like, drive oil into the well.

Knowledge of the conditions and of the processes going on in an oil reservoir during oil and gas production has been greatly increased during the past fifteen years as a consequence of theoretical and laboratory investigations, and the careful study of field data and behaviour. The problems are mainly of a physical and physico-chemical nature, and are far from completely solved.

Oil Recovery

Normally, oil fields are operated as commercial propositions. Hence the number of wells drilled will be that which, all things considered, will give the maximum profit. Wells drilled in excess of this number may give additional oil, but its value will not offset the additional costs incurred.

Under ordinary operating conditions the oil recovery is not the whole of that present in the reservoir, and complete recovery would not be very closely approached even by greatly increasing the numbers of wells and continuing production to infinitesimally low rates. Good current practice probably gives recoveries averaging 20–40 per cent. of the original oil in place for dissolved-gas drive, 30–80 per cent. for gas drive, and 60–80 per cent. for water drive.

Secondary Recovery Methods

After wells have declined in output to an uneconomically low rate, and in some circumstances before, methods which aim at increasing the oil recovery beyond the normal expectations of primary recovery are applied. In some instances artificial water drive has been successfully operated by injecting water through suitably placed wells and taking out oil through others. Artificial gas drive has also been employed. In other instances, beginning early in the field's life, gas is returned to the crestal part of the reservoir, for this can be beneficial in increasing recovery. In rare cases oil mining has been carried out. Galleries are driven in the sand and oil drains into them. Oil-bearing sand may be washed at the surface. Under average conditions mining cannot at present be regarded as a serious competitor of the normal methods of oil production.

Necessary studies before undertaking secondary recovery projects involve measurements of permeabilities, and porosities, and determination of the nature and amounts of the fluids remaining in the reservoir rock. Water may have to be treated before injection to avoid the formation of undesirable deposits in the reservoir ; new wells may have to be drilled, old ones re-conditioned and much equipment installed. These steps are essential if there is to be reasonable assurance that the project will be an economic and technical success.

Oil Production and Reserves

The world output of oil has shown an almost unbroken increase year by year since 1857 (Fig. 2). In 1943 the output is estimated to have been 2,271,818,000 barrels, making the aggregate output since 1857 43,964,981,000 barrels. Of this total U.S.A. has given 63·9 per cent. Russia and Venezuela are respectively second and third in importance, both as regards rate of production in recent years and total production.

Except in the case of U.S.A., estimates of available oil reserves have not been systematically prepared at different dates. In U.S.A. the estimates of unproduced reserves have increased throughout the years, and in terms of the rate of production at any date have generally been equivalent to more than ten years' supply. In recent years the known unproduced reserve has been equal to about fourteen times the current U.S. annual production. This figure must not be interpreted as meaning that if no more discoveries were made the production could be maintained at existing levels for fourteen years ; in practice the rate of production would soon begin to decline, and some oil would still be obtained many years after the fourteen years had elapsed. The rate of production is maintained and increased by virtue of new discoveries which give flush production, and in their absence efforts to maintain the production at the existing level would cause the ultimate recovery to be reduced, for this rate would not be the most efficient rate as the age of the fields increased.

At the end of 1943 the world recoverable oil reserves were estimated to be about 60,000 million barrels, 20,000 million barrels being in U.S.A., about 15,000 million barrels in the Persian Gulf

area and a like amount in the U.S.S.R. A study of the estimates of U.S. reserves at different dates makes it reasonable to suppose that these are not final figures, and for the Middle East alone there have been suggestions that an additional 25,000 million barrels are indicated. One writer considers that when the world's oil reserves have been fully explored it will be found that U.S.A. possessed less than 15 per cent. of the total.

It must be noted that these reserve figures refer to the oil recoverable by the methods and under the conditions of prices and markets obtaining at the time the estimates were made. Changes in these factors will affect the quantities ' available,' e.g. an increase in the price of oil might make it possible to operate some fields which cannot be profitably operated under present conditions.

Cross-section of the American Petroleum Industry in 1937.

Division.	Employees.	Investment.
	%	%
Production .	17·3	44·6
Pipe-line . .	3·5	7·6
Refining . .	12·2	25·6
Marketing .	67·0	22·2
Total .	100·0	100·0

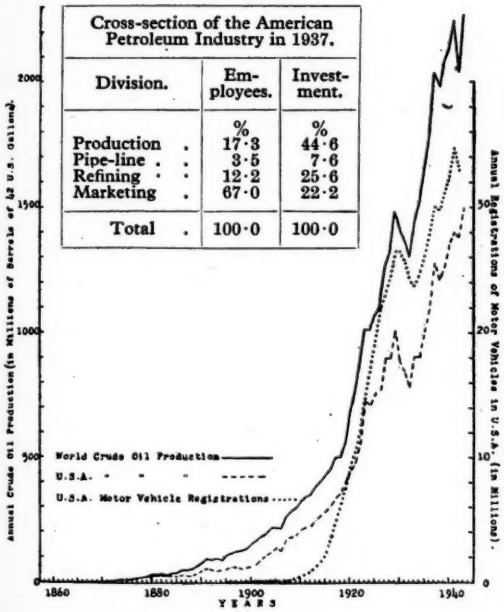


FIG. 2.

The above figures do not include the known natural gas reserves, which in the case of U.S.A. alone are possibly equivalent to 17,000,000,000 barrels of crude oil, and will provide substantial reserves elsewhere in the world.

Transportation

It is estimated that about a quarter of the oil produced in U.S.A. is emulsified with water, and demulsification by chemical or electrical means is carried out at the first opportunity. After this or any other necessary preliminary treatment the oil is ready to begin its journey to the refinery, a journey which may be by tanker, tank-car or pipe-line. Modern tankers provide some of the finest examples of the marine engineer's skill in design and construction. For many years pipe-lines have been constructed of seamless steel pipes, with all joints welded, two developments which have greatly reduced troubles due to leaks. The introduction of mechanical ditching machines, and machines which wrap the pipes with protective and insulating materials are among the many improvements due to the engineer and scientist.

Pipe-lines are of all sizes up to the 24 in. diameter pipe, some 1,200 miles long, running from Texas to the north-east coast of U.S.A. Its capacity of 300,000 barrels per day makes it equivalent in service to 25,000 railway tank-cars, or to 150 10,000-ton tankers.

Refining

Petroleum as obtained from a well is rarely suitable, without treatment, for the purposes for which it is needed. Some of the required products can be produced from crude petroleum by relatively simple processes. But in some cases modern requirements are exacting, and extensive re-modelling of the hydrocarbon molecules is frequently undertaken in order to meet them both qualitatively and quantitatively. This trend which was apparent thirty years ago, is becoming far more pronounced, and petroleum has become valuable not only for the products which can be extracted from it directly, but also for the ever-increasing range of products which can be prepared from it, by using it to provide the raw material for synthetic processes.

While some of the processes in the refining and associated sections of the oil industry have had origins which cannot be clearly attributed to scientific thought, the present state of development is largely due to the application of science. The chemist has made great advances in investigating the structure and properties of the compounds in crude petroleum and of materials which might be produced from them. He has conceived, and has carried out in the laboratory, processes which have been put into operation on a commercial scale through the efforts of the chemical engineer. The chemical engineer has drawn upon the metallurgist for metals and alloys to withstand high pressures, high temperatures, and corrosion ; upon the physicist for knowledge of heat transfer, of fluid flow, and of the equilibria between liquids and vapours ; upon the mechanical engineer and physicist for numerous automatic instruments and devices which have made cracking and many other complicated refinery operations possible and practicable with only a few of the men who would otherwise be needed, and with the reduction to a minimum of the element of human fallibility. These are but a few of the ways in which science has been applied in refinery and associated operations.

Distillation.—The compounds present in crude petroleum differ in their boiling points, a feature which makes it possible for petroleum to be divided into a series of fractions by the process of distillation. Each fraction is still a complex mixture of compounds, but the boiling-point range of the fraction is more restricted than that of the original petroleum. In the early days the petroleum was heated to a moderate temperature, and the vapours given off were collected and condensed to give the first fraction. The temperature was then raised, and further vapours came off, were collected and condensed to give the second fraction. This process was continued at higher temperatures, thus providing a series of fractions.

Distillation in stages has disadvantages and is replaced in the modern refinery by a continuous distillation process. In the continuous process the oil is pumped through a pipe-still (Fig. 3) in which it is heated to a temperature sufficiently high to vaporise all portions of the oil which are to be subjected to fractionation. From the pipe-still the hot oil and vapours pass into the fractionating tower.

The modern pipe-still has a coiled pipe so placed with respect to the combustion area of the furnace that the heat supplied is efficiently utilised, and increases the temperature of the flowing oil at the correct rate. The furnace temperature and the rate of flow of the oil are carefully controlled.

In the fractionating tower the vapours escaping from the oil pass upwards into successively cooler regions. Stretching across the tower are a series of plates called the rectifying plates, arranged in

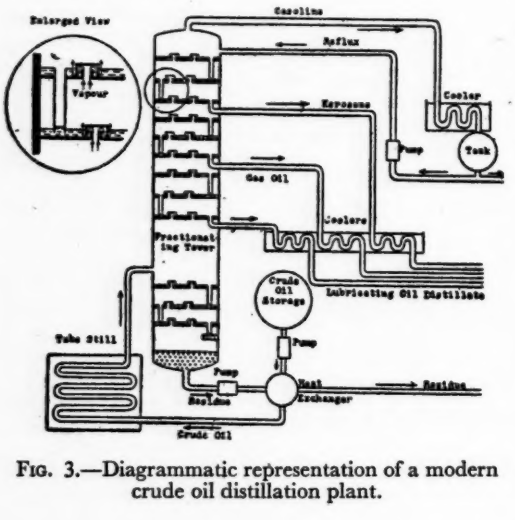


FIG. 3.—Diagrammatic representation of a modern crude oil distillation plant.

groups and so constructed that a layer of liquid can be maintained on each plate, any excess of liquid passing down to the next lower plate in a group. The plates have a series of perforations, each perforation having a short piece of tube on the upper side of the plate. This tube extends a short distance above the surface of the liquid maintained on the plate, and the lower edge of a wider inverted thimble placed over each tube dips into the liquid. Thus any vapours passing upwards through the perforations must pass through the liquid on the plate in order to escape under the edge of the thimble into the space above the plate. In this manner the rising vapours and the liquid on the plates are brought intimately into contact, causing an interchange whereby condensation from the vapours takes place, and at the same time there is evaporation of the most volatile components of the liquid. The combination of the fall in temperature upwards in the tower, and the scrubbing action of the liquid on the plates causes the vapours as they ascend gradually to become more volatile, while the descending liquids gradually become less volatile. The vapours passing out of the top of the tower are liquefied in condensers cooled by crude oil or water to give the gasoline fraction (straight-run gasoline). A pipe from the lowest plate of each group allows the other fractions to be run off, the uppermost pipe taking off the kerosene fraction, and the next one removing the gas-oil fraction. The products from the lower groups of plates vary with the type of oil being distilled.

The supply of descending liquid is maintained by pumping back into the upper part of the tower a part of the condensed vapours. This is known as the ' reflux,' and is carefully controlled to aid in the steady working of the tower.

The unvaporised oil from the pipe-still passes downwards over a series of bubble plates, the stripping plates, which are intended to remove the more volatile components of this oil, a process in which they are usually assisted by small quantities of steam blown into the tower. The nature of the residue depends on the type of crude oil. This residue passes out of the bottom of the tower.

All the products leaving the fractionating tower are hot, and pass through heat exchangers in which they give up some of their heat to the oil being pumped to the pipe-still. In this way furnace fuel is saved, as well as water for condensing and cooling, thus adding greatly to the economy of operation.

Most of the products from the fractionating tower require further treatment to make them suitable for use. Usually, the gasoline fraction requires only a simple chemical treatment to render it non-corrosive and of good odour, and also to improve its anti-knock properties, by the removal of certain sulphur compounds.

Gasolines from different sources are blended to give a finished gasoline which will perform properly under the conditions of altitude and temperature under which it is to be employed. Small amounts of lead tetra-ethyl may be added to improve the anti-knock properties of the gasoline.

The kerosene fraction is usually given chemical treatment similar to that applied to gasoline. Kerosene is used for heating, lighting and power purposes.

The gas oil fraction may be marketed in a practically unrefined state, or used as a basic material for cracking. It serves as a fuel in some types of internal combustion engine and in some of the smaller oil burners, and as a thinning agent. It is also employed as an absorbing agent for removing condensable constituents from gases. In cracking, the aim may be to produce gasoline, or to make oil gas, either as a separate product or as the enriching (carburetting) agent in water gas.

After removing the more volatile fractions by distillation, the residual portion of a crude oil with good lubricating oil fractions is further distilled under a pressure of about one-twentieth of an atmosphere, often with the introduction of steam. The use of low pressure and the introduction of steam enable distillation to take place at lower temperatures than would otherwise be necessary, thereby reducing the tendency towards the breaking up of the molecules. The distillation equipment consists of a pipe-still and a bubble-plate fractionating tower, but the latter must be considerably larger than for ordinary crude oil distillation, because of the large volume of low-density vapours produced. Several fractions are

separated from the vapours. The lighter fraction, known as wax distillate, contains crystalline paraffin wax and raw lubricating oil of the lighter type, and the heavier fraction contains amorphous wax and a more viscous lubricating oil. The residue usually consists of material from which asphalt may be prepared, or suitable for heavy fuel oil.

On chilling the wax distillate by artificial refrigeration crystalline wax separates, and the wax crystals are removed by filter-pressing. Removal of the amorphous wax (petrolatum) from the heavier distillate is achieved by chilling a solution of this distillate in naphtha or gasoline. The chilling temperature used depends on the congealing temperature desired in the finished lubricating oil. The amorphous wax is separated from the oil by passage through a high-speed centrifuge.

The wax-freed lubricating oils are often too dark, unstable in use, and of low lubricating value, due to the presence of non-lubricant asphalts and other undesirable constituents, which are removed by various means. Much lubricating oil is treated with sulphuric acid, which dissolves some of the undesirable substances and causes others to form a tarry sludge. After separation from the acid and sludge the oil is treated with caustic soda, or brought into contact with very finely divided fuller's earth at a moderately high temperature to neutralise the acidifying effect of the previous treatment. Contact with fuller's earth also causes further de-colorisation and adds stability to the oil. Nowadays the bulk of the lubricating oils are finished by using special solvents instead of employing the chemical and solvent effect of sulphuric acid. These special solvents preferentially dissolve the undesirable constituents in the lubricating oils, thus separating them from the desirable paraffin group when solvent and oil are brought into contact under suitable conditions.

Often the lubricating oils are sold as produced, but in other instances they are blended to give oils of intermediate viscosities, or they are compounded by the addition of fatty oils. Fatty oils are less resistant to oxidation and more liable to emulsification with water than are mineral oils. For many conditions of lubrication the addition of fatty oils to mineral lubricating oils offers no advantage, but blends of blown fatty oils (the blowing oxidises these oils and increases their viscosity and emulsifying properties) with mineral oils are used on bearings which are continually splashed with water, such as those of marine steam engines.

Crystalline wax is refined by one or more cycles of melting and solidifying—'sweating'—to remove much of the oil left among the filter-pressed crystals. Final percolation of the melted wax through fuller's earth improves the colour and odour of the wax. Crystalline wax is used in making candles and waxed wrapping papers, for electrical insulation, and in polishes, greases, etc.

Petrolatum may be refined by percolation through fuller's earth. High grade petrolatum ('vaseline') is used in pharmacy, while lower grades are used for protective purposes generally, and in cable insulation. An excess of petrolatum is produced, and therefore much of it is blended with other cracking-still charging stocks for transformation to cracked gasoline.

Asphaltic bitumen is a black solid or semi-solid material obtained as the end product in the distillation of certain types of crude oil after distilling off all the other products. The properties of asphaltic bitumen vary widely, and are strongly influenced by the method of preparation, blowing, steam refining, etc. It is used for road-making, in roofing felt, pipe-line coatings, water-proof paper, and in the electrical industry for a variety of purposes.

Cracking

The compounds in mineral oils undergo decomposition when heated to sufficiently high temperatures. In this process, termed cracking, complex molecules such as those of fuel oil produce lighter hydrocarbons on one hand, and still heavier hydrocarbons on the other. (While theoretically cracking breaks down all the heavy molecules into lighter units, some of these units are highly reactive and combine to form molecules even larger than those in the original oil.) The decomposition can be controlled by careful regulation of the time during which the oil is heated. Cracking makes possible the manufacture of more valuable products such as gasoline from surplus material such as gas oil and heavier oils.

The oil to be cracked is heated in a pipe-still to a high temperature and under a pressure greater than atmospheric, and then it passes into a bubble-plate tower for fractionation. The heavier fractions produced are recycled for further cracking.

The temperatures and pressures employed depend on the type of process. In liquid-phase cracking the temperatures may be 450°–540° C., and the pressures 200–900 lb./in.^{2}; in vapour-phase cracking the temperatures may be 540°–570° C., and the pressures 25–50 lb./in.^{2}. In catalytic cracking the operating temperatures are 55–110° C. lower than in the purely thermal cracking processes.

The principles on which the pipe-stills and other equipment used in cracking are based are the same as those for straightforward distillation, with modifications to cope with higher temperatures and pressures, and with corrosion. The combating of corrosion may require the use of alloy-steel equipment.

Automatic control instruments are widely used in cracking plant, as in other refinery plant. When furnace temperatures change beyond the prescribed limits instruments reduce or increase the fuel supply; they adjust the levels of liquids in the bottom of the fractionating tower and in other vessels when necessary; other devices reduce or raise the pressures at various points, or change the rates of flow of liquids when the recording and indicating instruments show a wrong condition.

On cracking, a fairly good quality gas oil may yield over 60 per cent. of gasoline, 25 per cent. of residual fuel oil, 10 per cent. of gas and less than 1 per cent. of coke. The gasoline differs chemically from gasoline produced from crude oil by simple distillation. Cracked gasoline may contain only 40 per cent. of paraffinic hydrocarbons,

20 per cent. of aromatic hydrocarbons and 40 per cent. of naphthenic, olefinic and similar hydrocarbons whereas there may be 70–90 per cent. of paraffinic and only 5 per cent. of aromatic hydrocarbons in a straight-run gasoline. The reduction in the amount of paraffinic hydrocarbons as a result of cracking causes the cracked gasoline to have superior anti-knock properties to the straight-run gasoline. Thus cracking, which was first applied to increase the production of kerosene, and later extensively to the production of gasoline with the expansion in the use of the motor car, also provides a gasoline which has permitted the employment of more efficient internal combustion engines.

Knocking is a phenomenon with which motor drivers are familiar. It occurs, for example, when the speed of the motor engine is diminished under an increasing load during steep hill climbs. Among its harmful features knocking reduces the power output in relation to the gasoline consumption. The higher the compression ratio of the engine the greater is the tendency to knock with a given fuel. Knocking is therefore a most serious matter, since high compression increases the efficiency and economy of engines. The production of high anti-knock gasolines by cracking and by other means such as the addition of small amounts of lead tetra-ethyl has been an important factor in the improvement of the performance of the aeroplane and motor car.

Hydrogenation and other Processes

A process which combines cracking and hydrogenation is operated in some countries, generally for the production of gasoline, but sometimes for the production of lubricating oils. High pressures and temperatures are employed, and the raw materials are crude oil or oil residues. The process eliminates the formation of the heavy material which is normally one of the products of ordinary cracking.

At times, low-grade gasolines are subjected to catalytic re-forming, a process which converts some of the hydrocarbons into hydrocarbons of a different type with superior anti-knock properties.

Refinery gases produced during cracking operations, and gas from oil or gas wells after cracking, contain unsaturated hydrocarbons. The unsaturated hydrocarbon molecules can be caused to polymerise, *i.e.* to combine together to form larger molecules, thereby yielding products from which gasolines are obtained. Alternatively, good anti-knock gasolines can be produced by the interaction of refinery gases with some of the compounds in field gases. Both processes require high temperatures and pressures, unless a catalyst is employed, in which case rather lower temperatures can be used.

During recent years hydrocarbons in or produced from petroleum, and especially those hydrocarbons in the gases produced in cracking, have formed the raw material for numerous synthetic processes which have provided many valuable and new products. Amongst products synthesised directly or indirectly from petroleum are certain general and local anaesthetics, hypnotic drugs, glycerol and all the commonly used alcohols, insecticides, plastics, artificial rubbers, explosives, solvents, fuels, and substances for ripening and preserving fruits.

Natural Gas and its Products

The gas produced with oil often contains appreciable quantities of hydrocarbons which can be recovered in liquid form by one of several processes. The product, known as natural gasoline, is highly volatile, and is generally blended with other gasolines.

Two of the hydrocarbons present in natural gases of the above type, and having normal boiling points rather lower than atmospheric temperature, are sometimes recovered and separated by fractional distillation. These hydrocarbons can be stored in the liquid state at pressures of 80–200 lb./in.^{2}. They are sold in steel cylinders, and are quite widely used as a substitute for coal gas.

Natural gas from which the more readily condensable hydrocarbons have been removed, is used for heating, lighting and power. Much natural gas is used in manufacturing carbon black for pigments, inks, and toughening rubber tyres.

Petroleum Substitutes

Shale Oil

Oil shales are rocks containing considerable amounts of organic matter, probably of vegetable origin. This organic matter is intimately mixed with fine-grained mineral matter. On heating oil shales in retorts under suitable conditions one of the products is an oily distillate. This oily distillate is undoubtedly produced by cracking of the carbonaceous matter, and varies in composition with changes in the retorting conditions. It differs from petroleum in having considerable amounts of unsaturated hydrocarbons in its lighter fractions. On refining crude shale oil can be made to give gasoline, kerosene, gas oil, fuel oil, lubricating oil and wax. Alternatively, the crude shale oil or a fraction of it may be cracked to increase its yield of gasoline.

Oils from Coal

When coals are carbonised, as in the manufacture of coal gas and coke, or smokeless fuel, oily or tarry liquids are produced. The amount and composition of these liquids vary with the type of coal and with the retorting conditions. The crude product obtained by low-temperature carbonisation can be fractionated to yield a good gasoline and also a fuel oil. In high temperature carbonisation, as in gas and coke manufacture, motor benzole and solvents, and a host of other products including fuel oil, tar acids, naphthalene, creosote, disinfectants, anthracene and pitch, can be obtained by scrubbing the gas and fractionating the tar. These materials form the basis of many other products, synthetic and otherwise, ranging from dyestuffs, drugs, explosives, insecticides and waxes, to synthetic perfumes.

Coal tars or fractions of coal tars may be hydrogenated to produce motor spirit.

A mixture of carbon monoxide and hydrogen can be manufactured in a variety of ways from bituminous and brown coals, and even from peats. This mixture is used as the starting-point for the catalytic synthesis of hydrocarbons at relatively

low temperatures and pressures. Fractionation of the hydrocarbon products yields a gasoline, diesel oil and wax. The gasoline may be improved by cracking or other processes. Certain types of hydrocarbons in the primary product may be polymerised to give good quality lubricating oils, while cracking of the waxy part of the primary product provides further material for polymerisation to lubricating oils. The wax may be used in candle-making, cosmetics, and electrical insulation, or it may be oxidised to form crude synthetic fatty acids, from which refined acids may be prepared and utilised in the manufacture of soaps and even of edible fats. The synthetic production of both glycerol and fatty acids has thus rendered possible the manufacture from mineral raw materials of substances which hitherto could be obtained only from animal and vegetable sources.

It may be noted that the soaps and edible fats made from the synthetic fatty acid mixture differ from the natural products in containing fatty acid components with odd as well as even numbers of carbon atoms in the molecule. Tests on human beings and animals show that this difference does not appear to affect the digestibility of the synthetic fats.

Under high pressures and moderately high temperatures, and in the presence of catalysts, coal, lignite and carbonised peat can be hydrogenated to yield synthetic oils, and from these motor spirit and diesel oil can be obtained. In some cases up to 95 per cent. of the dry, ash-free substance can be converted to liquid and gaseous products by hydrogenation. Alternatively, the initial step in the formation of hydrocarbons, starting from coal, may be the manufacture of calcium carbide, and the production of acetylene from this compound.

Alcohol

Alcohols have been widely employed as a petroleum substitute for blending with motor fuel in Europe. Methyl alcohol is generally synthesised, but ethyl alcohol is manufactured largely by the fermentation of vegetable matter (potatoes, rye, sugar-beet, molasses, etc.).

In the foregoing necessarily brief account of the production and preparation of oils, some of the ways in which science has been applied have been indicated. But there are many other ways in which science has been of service directly or indirectly. Our knowledge of the compounds present in oils, their composition and structure, is entirely derived from scientific investigations ; science has devised many of the methods used in testing oils and their products ; science has also played a part in creating uses for oils and for the products derived from them.

The applications of science in the refining and allied operations of the petroleum and petroleum substitute industries are probably more widely known and more generally appreciated than the applications of science in other phases of these industries. Science has nevertheless made important contributions towards the solution of the complex and difficult problems involved in the discovery and development of oil fields. The large sums of money spent on geological and geophysical work by oil companies are some indication of the value which these companies attach to the application of science in searching for oil fields. In the development of oil fields the oil industry draws upon many sciences, and although many of the applications are to details, or of an ancillary nature, their contributions are none the less most important.

In the refining and allied sides of the oil industry the application of science in synthetic operations has created a state of affairs in which it is becoming possible to produce a given product starting from any one of several different raw materials, such as coals, petroleum, or vegetable matter. It may, however, never be economically desirable to operate some of the processes extensively, because some of the raw materials may be of greater value for other purposes. Egloff has summarised the position in observing that ' any synthetic product desired can be produced at a price,' and that all the synthetic products that have been produced in organic chemistry, some 500,000 in all, can be made, starting from methane.

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PLANT BREEDING AND GENETICS TO-DAY

By Dr. P. S. Hudson

Plant breeding is in most languages synonymous with the word ' selection ' and, indeed, the principle of selection lies at the root of all systems of plant improvement. Some sort of selection has been practised, consciously or unconsciously, by plant cultivators since the very earliest times. For instance, we have documentary evidence to show that the ancient Egyptians pollinated their date palms by hand and that they chose the best forms for furnishing the pollen. This was a primitive, but probably quite efficient, method of plant breeding, and in essentials the methods have remained unchanged up to the present day. Many vegetable growers save their own seed from year to year, carefully selecting each year the best and most sturdy plants as seed bearers and in this way a number of excellent strains of cabbage, Brussels sprouts and other popular vegetables have been built up and are jealously guarded almost as family secrets by the growers who produce them. Nor is this method of plant selection confined to the dilettante or amateur gardener. It has served as the basis for many of the best achievements of professional plant breeders. Sugar beet for instance was a thing unknown two centuries ago. Marggraf, in the middle of the eighteenth century, discovered that the beet root contained a sugar which resembled cane sugar in all its properties, but it was not until the end of the eighteenth century that Achard began a systematic process of selection with the deliberate object of raising the sugar content and this he did with such success that, from an original population of roots containing no more than about 2 per cent. of sugar, he produced, by continued selection over a number of generations, a strain that contained 10 per cent. or more of sugar. During the ensuing years, the Napoleonic wars between England and France caused a serious crisis in French national economy ; the country was cut off from sources of imported foodstuffs and every effort was made to make the country self-supporting. Sugar was one of the commodities which at first had defeated all attempts to provide a home supply. But this new discovery, that by a simple process of selection the sugar content of a common root could be multiplied, gave a new stimulus to the selection work, and by 1815 a factory for producing sugar from sugar beet was working commercially in France. The subsequent history of Europe has been so turbulent that the stimulus to provide home-grown sugar has never been lacking, and efforts to raise the sugar content of the roots have never slackened. In the next hundred years the percentage sugar content has been almost doubled and there is no evidence that the limit has been reached, although of course progress is naturally much slower and more difficult to achieve.

The sugar beet furnishes an instance of how an entirely new agricultural crop plant can be created by individual plant selection. Another equally striking instance can be quoted from modern times. This is the so-called ' sweet lupin.' It is well known that the wild forms corresponding to many of the cultivated leguminous plants such as the pea, lentil, vetch, etc., contain a bitter element or alkaloid in the seed, which is thus rendered unpalatable and even poisonous. The cultivated forms must presumably have originated in the first place from some chance forms without the alkaloid which have arisen among the common wild population, and the possibility naturally suggested itself that, if a rigorous search were made, analogous forms might be found in the lupin, in which so far no ' sweet ' forms were known. Such a search was made by Sengbusch in Germany, who succeeded in isolating lines with as little as 0·01 per cent. total alkaloid. The full details of the procedure, however, were not published, and the new strains were carefully guarded. Russian botanists, however, working at the Institute of Plant Industry, Leningrad, undertook a search on the same lines and elaborated their own method, which was published in full, for the rapid estimation of minute quantities of alkaloid in a seed. By means of this method as many as 1000 plants could be tested by one worker per day, thus making it possible for very extensive observations to be made on all the more valuable species of lupin for agronomic purposes, gathered from every possible source in any part of the world where lupins are grown. Enormous numbers of each species were tested, and the results showed that the alkaloid content of lupins is subject to wide variation, and that the forms of certain regions are characterised by higher alkaloid content than others. Thus in *Lupinus luteus* the alkaloid was low in seeds obtained from Holland and Bremen, these samples containing high proportions of alkaloid-free seeds, some as much as 100 per cent. The samples from most other regions contained few, or, more usually, no alkaloid-free forms. As an illustration of the rarity of the desired forms in cases such as this, it may be pointed out that in *L. angusti-*

folius only 1 out of 31,591 plants examined, from the most varied sources, was free from alkaloid. In some of the other species examined no form entirely free from alkaloid was found though, in all species, forms with very low alkaloid content appeared. On going into the question of the geographical distribution of these low alkaloid forms, it was found that they tend to be concentrated in the western Mediterranean countries, and a more thorough investigation still of the forms, both cultivated and wild, occurring in these countries, was then undertaken, in consequence of which further sweet forms were discovered. These sweet lupins have been multiplied and have all been found to breed true for the absence of alkaloid. They constitute an exceedingly valuable new source of protein for use both green and as seed for feeding to stock, and the unripe seeds form a new green vegetable for human consumption. The cultivation of sweet lupins on the continent of Europe has expanded very rapidly and its introduction into other countries has also been attended with success, especially in New Zealand. In a recent bulletin of the Canterbury Chamber of Commerce (1942) a report is given of feeding trials in which sweet blue lupins were fed to young lambs and the increase in weight compared with that from rape, which is the normal feeding stuff. Ninety lambs grazed on the sweet lupins gained an average of 11·87 lb. per head in comparison with lambs fed on an equal area of rape, which gained 9·76 lb. per head—thus a difference of 2·11 lb. in favour of the lupins. The lupin was found, moreover, to yield a more certain crop than the rape and to be much less susceptible to pests and diseases. The sweet lupin might well repay a trial in other stock-raising countries as an alternative source of fodder. It is further stated that a flour rich in protein, similar to soya bean flour in properties and suitable for human consumption, can be prepared from the seed.

The examples of sugar beet and sweet lupin illustrate how it is possible under the stress of national crises by plant selection to create entirely new crop plants—the sugar beet under the stress of the Napoleonic blockade, the sweet lupin under the equally critical conditions of Germany after the first World War and Russia after the October revolution. However, plant breeders are not always required to produce entirely new crop plants. National circumstances frequently make it desirable to introduce into cultivation a plant which has previously not been grown in the country but imported from abroad. For instance the flax grown in the British Isles before the last war was grown entirely from imported seed, most of which came from Russia. The supplies of seed were cut off by the war and efforts were made both by private breeders and by official institutions to produce a local source of seed. Again recourse was had to individual plant selection and the results of selection pursued over a number of consecutive years surpassed all expectation. Not only was a solution of the problem of home-grown seed provided, but new flax varieties were produced which proved distinctly superior to those previously grown from imported seeds. The first of these was named J.W.S., after Mr. J. W. Stewart, the pioneer worker in this field; and later varieties such as Stormont Gossamer and Stormont Cirrus, raised by a continuation of the same process, have yielded over 50 per cent. more scutched fibre than the old original commercial types.

Severe crises in the history of nations are not always produced by wars. Nature herself sometimes provokes catastrophes as baleful as those that the ingenuity of man can devise. A familiar instance of such a natural catastrophe was the Irish potato famine in 1846. At that time, as is indeed largely the case still to-day, the Irish peasant had one main source of food, the potato. The appearance of the blight fungus, *Phytophthora infestans*, in 1845 and the epidemic proportions it reached in the following year, caused the complete failure of the potato crop in Ireland, and an entire people was faced with starvation. The political and economic consequences of the Potato Famine are well known. The obvious way to prevent the repetition of the catastrophe was to search for a potato that should be immune from the disease, and this search is still in progress. Immune potatoes have indeed been found, but their utilisation has been attended with a variety of difficulties which will be discussed later. An example of the immediate solution of a similar problem is furnished by the cotton crop. An almost similar catastrophe threatened the cotton crop in South Africa in the early years of the present century when plants became attacked by the jassid insect, *Chlorita fascialis*, which harbours on the leaf and causes it to wither. So severe were the attacks that it was at one time thought that cotton cultivation throughout the southern portion of the African continent was doomed. It was noticed, however, that certain plants tended to be less severely attacked than others. One plant in particular attracted attention on account of its unusual health and vigour, and seed from this plant was carefully saved by Parnell and served as the basis for multiplication of a new stock, which ultimately received the name U4. This cotton retained the capacity to resist the attack of the jassid insect which

characterised the parent plant, and its cultivation rapidly extended to the whole territory of south, east, and east-central Africa and beyond. In addition to its resistance the U4 cotton exhibited many other desirable features, such as heavy yielding ability and a wide adaptation to varying climatic conditions, and its cultivation has now extended far beyond the areas for which it was originally designed.

The menace of disease has been overcome in a great many crops by this simple method of singling out plants that resist attack. Unfortunately the method is not always so relatively straightforward as it was in the case of the U4 cotton described above, which owes much of its success to its happy combination of resistance and other favourable characters which recommended it to the growers. More often than not, however, in other crops a resistant plant, if it is found, proves to be defective in one or more of the other characters that are essential for successful cultivation. The discovery of a resistant plant of such a type then provides a solution to only half the problem. The problem of combining the disease resistance of the resistant plant with the valuable agricultural and industrial characters of the commonly grown susceptible forms still remains.

Hybridisation

This can only be done by hybridisation or crossing together the two forms containing the two characters, or groups of characters, that it is desired to combine, in much the same way as stock breeders combine the characters of their pedigree sires with those of pedigree dams to produce the champion that is to carry away all the prizes. The method of hybridisation applied to plants is no new thing. The first extensive experiments on plant hybridisation were made as early as 1760 by the Swabian botanist Kölreuter, but it was applied to the practical improvement of plants only at a much later date. By the end of the nineteenth century, however, this method had been used extensively, and John Farrer in Australia and Dr. Charles Saunders and his two sons in Canada had by its means produced improved forms of wheat which influenced not only the agriculture but the entire history of these countries. Then, quite unexpectedly, a much more scientific way of using plant hybridisation was discovered. A modest monk named Gregor Mendel, working quietly and patiently in the solitude of an Austrian monastery, was able to discover the secret of the inheritance of characters, a secret that had escaped all previous searchers. He found how the characters of the parents, be it in plants, in animals or in man, are passed on to their offspring. The secret can be expressed briefly in one word—'recombination.' If the father of a family has one characteristic, say tall stature, and the mother has another, say dark hair, some of the children may be both tall and dark. Features from both parents, that is to say, may be found united in a single individual. Other children may, on the other hand, have neither of the two characters and so be short and fair.

Professor Biffen in England was one of the first to realise that the laws of heredity discovered by the monk Mendel could be used in plant breeding. It should be possible, said Professor Biffen, by suitable crossing, to combine in one individual the desirable features at present found scattered among different varieties. He naturally turned his attention to the problem which, as we have just seen, is one of the most urgent of all for agriculture—the problem of finding plants that resist disease. Would such a character obey the same laws of inheritance as the more simple characteristics dealt with by Mendel? Such was the question that Biffen set himself to solve. Yellow rust was one of the most serious pests of wheat in Britain. Biffen collected wheat from all parts of the world until he found a variety that could not be attacked by this yellow rust. This was a Russian form which unfortunately did not grow well in the climate of England. He crossed it with one of the English types of wheat and carefully studied the plants in the offspring. These showed him that the valuable power to resist the rust attack was inherited, by recombination, exactly in the way Mendel had explained.

Thousands and thousands of the cross-bred plants were examined by Biffen and he found one which, like one of its parents, was able to resist the disease, and like its other parent was suitable for the English soil and climate. From this one plant he raised a stock of seed and sent it out to farmers, and the new strain proved to be one of the best kinds of wheat England had ever had. It remains so to the present day. It was named 'Little Joss.'

The method of hybridisation used by Biffen in the production of Little Joss wheat was quickly applied to other plant-breeding problems and has now become the standard method on which all systems of plant improvement are based. The breeder faced with the task of improving any given plant first applies the simple selection method described above and gets whatever improvement he can by this means; but sooner or later he finds that he is coming to the end of the progress that is possible by this means alone and must have

recourse to the crossing technique in order to combine a number of desirable qualities, some of which are present in one variety or strain, others in another. Almost every day we hear of some new and improved race of crop plant, superior to its predecessors in, say, yielding ability, or cooking quality, or size and flavour of fruit, or resistance to some disease or other, and in this way the almost endless variety of our agricultural crop varieties has come into existence. There were for instance some 140 varieties of wheat alone obtainable on the English market in the years immediately preceding the second world war, and new ones, improved in one respect or another, are constantly being added.

It will be seen that this constant improvement of the race can only be effected if all the potentialities of the crop in question are available ; in other words the breeder must make sure that all the valuable qualities which exist in the crop are known to him and are present in the forms he is working with. It is conceivable, for instance, that one of the qualities that a wheat breeder most wishes to introduce into his plants, say the capacity to stand up to some particular disease, may be present in some little-known wheat strain grown in some out-of-the-way corner of the globe unknown to him. Many of the wheats grown in Abyssinia, for instance, are known to have a number of characters such as purple grains and other unusual features which are unknown in all other parts of the world. Many a plant breeder, in pondering over this situation, has been assailed by doubts and asked himself whether he might not be spared all his pains if he could only pick up the desired form ready-made in one of these unknown or forgotten regions that has not yet been studied. The only solution, of course, is to make a complete survey of the whole world and a systematic study of the forms of crop plants collected ; in this way one would be in a position to say what qualities do and what do not exist in a given plant. The Russian botanists under N. I. Vavilov set themselves to do this elaborate world survey in the early years after the revolution and the results surpassed all expectations. Rich and quite unexpected sources of economic plants were found and the range of variation within each plant was found to be much greater than had ever been previously suspected. Not only new plant characters or varieties but new species were discovered. Even in wheat, which was one of the most widely investigated of the cultivated plants, several new species, hitherto completely unknown, were found ; one of these, known as *Triticum Timopheevi*, has aroused particular interest since it is resistant to almost every known disease of wheat. Attempts were immediately made to introduce this disease resistance into cultivated wheats by hybridisation and, although initial difficulties were experienced, it seems that the efforts have now been crowned with success, thanks to the use of special methods, to which we shall return later.

An essentially similar situation was found in respect of the other crop plants. In barley, for instance, forms were found that were adapted to extreme conditions either of moisture or of drought, others with smooth awns or naked grains, or resistance to the frit-fly and so on. Among fruit trees, apricots that will survive 72 degrees of frost, blackberries with soft spines, edible honeysuckle and mountain ash, frost resistant vines and disease resistant forms of many others are among the more interesting of the types discovered.

The extensive plant-collecting expeditions in which the Russian botanists engaged in in order to assemble all this vast amount of materials also served to shed a great deal of new light on the distribution of cultivated plants over the globe. It was found that cultivated plants, contrary to previous tradition, are subject to very much the same laws of distribution as wild plants, and that this distribution has in a great number of cases been very little altered by man's agency. Each plant studied has proved to be subject to a quite regular law of distribution, which takes the form of radiation from a given centre. This centre, which usually embraces a relatively limited area of country, is characterised by an exceptional abundance of varieties and forms. Quite often no two forms are alike, and the number to be found in this small confined space far exceeds the total number occurring in the whole of the rest of the area of distribution of the plant in question. The same applies to the number of plant characters present, for a greater number and variety of characters are to be found in this small zone than in all the rest of the area. Vavilov, arguing from this particular type of distribution and the hereditary nature of the forms he found at the so-called ' centres of diversity ' of cultivated plants, concluded that these centres were in reality the centres at which the groups of plants in question had originated. Otherwise how was it possible to explain the astonishing wealth and variety of, say, the bread cereals in Abyssinia and the neighbouring countries and their total absence in Asia and America ; or of the oranges and other citrus fruits in India and China and their absence in Europe and America ; or again, of maize, tobacco, tomatoes and

potatoes in South America and their total absence, until they were introduced, in Europe and Asia ? It cannot be argued that the absence of certain plants in certain continents is because climatic conditions are unsuitable and they will not grow there. Think of the tomato, for instance, introduced originally from South America to Europe, and now grown successfully in almost every country in the world. Or the citrus fruits, once confined to Asia, whence they were brought by Arab traders to the Near East and the Mediterranean countries, where they have become one of the predominant crops, and from there have spread to South Africa, U.S.A., South America and throughout the sub-tropical world.

One of the earliest plant introductions from South America was the potato. It is now known, through the recent researches of Dr. Salaman, that the first potato to come to Europe was not the proverbial one brought by Sir Walter Raleigh, or even Sir Francis Drake, in whose honour a statue was erected in the little German town of Offenburg to celebrate the event. The evidence shows that potatoes were introduced into Spain as early as the year 1570 or even before. There are records of their being purchased by the Hospital de la Sangre at Seville in 1573, presumably for the use of the patients, since the potato was at that time a great curiosity and was credited with strong medicinal powers. There was at first much confusion as to the identity of the plant. Its very name was assigned erroneously through its being confused with the ' batata ' or sweet potato, which had become known somewhat earlier. From Spain the potato was sent to Italy, to the Pope, where it received the name tartuffi or tartufoli (truffles), and thence to Vienna, where the name was transformed again into the Kartoffel of modern German. This name has also been adopted by the Russians. Apparently the potato did not reach England till about 1586 and remained very much of a curiosity in rich men's gardens. It was in Ireland that it found almost immediate acceptance as the ' poor man's food.' To-day the potato is cultivated throughout the world and is one of man's staple foods. The number of agricultural varieties recorded can be counted in hundreds. Yet as far as we are able to judge from the information at hand, all these innumerable varieties have arisen ultimately from the first few tubers that were introduced into Europe three-and-a-half centuries ago ; at least there is no evidence to show that any later introductions of material from South America were made, or, if they were, that they had any material effect on potato breeding. The entire range of types known in our present-day potatoes, then, has arisen by a process of recombination and better recombination of the characters contained in the original material brought over in Queen Elizabeth's time. What must have been the astonishment of the Russian botanists, therefore, when they sent their expeditions to the South American Andes, to find, growing in the Cordilleras of Bolivia and Peru, hundreds again of different potato types, all as different as could be from the potatoes grown in Europe and elsewhere. They found potatoes of all conceivable shapes and sizes, some long and sinuous like a serpent, some small and round, others with curious markings like the head of an animal or man ; tubers of all colours, ranging from inky black, through various shades of purple and pink to pale cream colour, were found, and there were many differences of flavour and consistency too. Most of these forms are cultivated by the local Indians and are given distinctive, often highly descriptive, names. That these potatoes have been used by the local inhabitants from time immemorial is shown by the discovery among the ancient Indian pottery of quaint vessels in the shape of potato tubers, with the eyes and all, and of others, more grotesque in shape, where the head of a man or animal is depicted with eyes resembling those of a potato.

From all this the Russians concluded that they had actually found the birthplace of the cultivated potato. Many of the primitive potatoes found there show surprising resemblances to those depicted in the first published descriptions of the potato by the early herbalists. Their characteristic features have thus been gradually lost in many generations of breeding. Many others, however, have in fact never been known in Europe or the rest of the world, owing to the unrepresentative and random nature of the samples that served for introduction. The practical importance of this discovery lies in the fact that some of these characters that had previously been unknown are of great agricultural importance. One of these is frost resistance ; the potato has never been regarded as a hardy plant, but now it is found that frosts occur almost every night in the higher areas of potato cultivation in the Andes, which in places go up to almost 14,000 feet, and the potatoes come through undamaged. Such hardiness, if it could be transferred to our common potatoes, would enable immense northern areas in countries like Canada to grow potatoes for the first time. We have already seen what terrible consequences the ravages of disease, like potato blight, can have if left unchecked, and so far no satisfactory control for blight disease has been forthcoming. Some of the primitive species found in Mexico, however, are

immune from blight, and it only remains to transfer this immunity to the domestic races for a complete solution of the problem to be provided.

Interspecific Crosses

Unfortunately this transference of characters from one species to another is not always as easy as might be desired. In U4 cotton, as we saw above, the desired resistance was found in a common agricultural variety, which could be introduced immediately into cultivation. Even if the desired resistance is in some variety of otherwise undesirable type, it can generally be transferred by the method of recombination if the variety belongs to the same botanical species, as we saw in the case of Little Joss wheat. If, however, the resistance we are seeking is only to be found in a member of a different species, as in the potatoes and many other plants, a number of very serious obstacles are encountered. Hybrids between different plant species are often only partially fertile and may even be completely sterile. The recombination of the characters is often very irregular and unpredictable and not at all in conformity with the Mendelian laws. These irregularities in inheritance in interspecific crosses were at first a great mystery, but an explanation of at least a great many of them was provided by a study of the 'chromosomes.' These are the organs that are responsible—as is proved by an incontrovertible body of evidence—for the transference of most of the hereditary characters of the plant. They take the form of minute thread-like bodies within the nucleus of the cell. They can be distinguished only at certain periods of the life of the cell—cell division—and then only under extremely high powers of the microscope. In spite of their minute size, they are the most important bodies with which the breeder has to deal. Each plant has a definite number, it may be 3, it may be over 50, and this number is usually characteristic for the species. We have reason to believe that each chromosome preserves its identity during the whole life of the plant and is responsible for a particular group of hereditary characters. In the reproductive cells of a normal plant (the male pollen cells and the female egg cells) each chromosome is different from all the others—different in the hereditary characters (or factors for characters as we choose to call them) which it carries and, in many instances, different even in shape or in size. When fertilisation is effected by applying the pollen of one flower to the female organ of another, two of these cells unite and result in a new cell with twice as many chromosomes as the reproductive cells contained. From the multiplications of this cell a new individual arises.

Always, therefore, each cell of the mature plant contains twice as many chromosomes as each reproductive cell, being composed of the chromosome sets of both male and female parents. These chromosomes are seen to unite in pairs and, in plants whose individual chromosomes differ in size, it is seen that the ones of corresponding size from the two parental cells pair with each other. The chromosomes that pair are therefore called homologous chromosomes (1 and 1^1, 2 and 2^2, etc.). The homologous chromosomes entering into fertilisation may contain identical hereditary factors, as in the union of a male and female nucleus from the same plant of a pure line, or they may differ in some of the factors, as in a cross between two different types of individuals of the same species.

The new individual resulting from this fertilisation keeps the double chromosome number until reproductive cells are formed anew, when the old number is again arrived at by a process in which the homologous chromosomes separate and enter into different cells, without previous division.

From this very brief description of the reproductive processes, it will be gathered that when the two cells entering into fertilisation contain different chromosome numbers, the smooth working of the process as described above becomes impossible. This is precisely what occurs in the cross between the blight resistant potato from Mexico and the common domestic potato. The blight resistant potato (*Solanum demissum*) has 72 chromosomes and the domestic potato has 48. It is possible to get a hybrid individual from a cross between these two, but the hybrid has an unbalanced chromosome number, 36 from the Mexican parent and 24 from the domestic parent. The regular pairing of homologous chromosomes is therefore impossible, since, even if the 24 domestic chromosomes pair with 24 of the Mexican chromosomes, there remain 12 Mexican chromosomes unpaired. For this reason, at the time of formation of the reproductive cells with the reduced number of chromosomes, the behaviour of these unpaired chromosomes is very irregular ; some may go into one of the two cells and others into the other, some may divide and the respective halves go into different cells, and some may even get left behind altogether and be lost. This results in the possession of very variable and irregular chromosome numbers by the daughter cells so produced, some of which have numbers closely approximating to that of the Mexican parent, others to that of the domestic parent, and the majority intermediate between these two, and all exhibit sterility to a greater or lesser

degree. Breeding from interspecific crosses then is seen to be a very complicated business and has often been pronounced to be unprofitable. Results of practical importance have nevertheless been achieved by its means. Blight resistant potatoes of first-rate commercial quality have now been produced by Dr. Black of the Scottish Society for Research in Plant Breeding by crossing the Mexican *S. demissum* potato with domestic forms. The first outstanding example of the use of the method was the production of the wheat variety 'Hope,' which has done so much towards the solution of the problem of supplying rust-resistant wheats to Canada and North America, and which was produced from a cross between the common bread wheat (*Triticum vulgare*) and Yaroslav emmer (*T. dicoccum*) two species differing in chromosome number. The cross was made by McFadden in 1916; only one hybrid plant was obtained but this produced 100 shrivelled seeds, from which a second generation and a very large third generation were grown. By only growing on the plump grains, a large fourth generation was produced which contained four common wheat plants, possessed nevertheless of all the desired characters of the emmer, i.e. resistance to stem and leaf rust. By continued selection good lines were obtained possessing resistance to drought, others to damage by hail and tip-burn, as well as to the most virulent forms of stem rust and bunt. These lines are of good quality, have 42 chromosomes like the other bread wheats, and cross with perfect ease with other varieties of the group.

Many other instances may be quoted of the successful use of interspecific hybridisation in the solution of economic problems. One of the most interesting stories in the history of plant breeding is the production of sugar canes in Java, resistant to diseases such as sereh and mosaic. Round about the year 1880 the Java sugar industry was threatened with collapse on account of competition from sugar-beet and the serious losses caused by a new disease known as sereh. Chunnee, a wild variety (*Saccharum spontaneum*) discovered in northern India, was immune to this disease, but, on account of the specific differences, crosses between it and the cultivated canes (*S. officinarum*) were not successful for a considerable time. A method was gradually evolved of crossing the hybrids back to *S. officinarum* and conserving those individuals in the progeny which inherited the disease resistance. When it was discovered that Kassoer, a wild strain resistant both to sereh and mosaic, was itself a product of a cross between the same two species, this method was pursued with more vigour and, as a result of repeated crossing with cultivated forms (locally termed 'ennobling'), new strains were evolved which, while showing enormous advances in the way of yield and sugar content, yet possessed a sufficient degree of resistance to make their cultivation practicable. The Java canes have been the salvation of many sugar-growing countries where these diseases were rife, and have themselves formed the starting point of many other successful series of crosses in other sugar-growing countries throughout the world. An equally famous series of canes has been developed at Coimbatore in south India by almost identical methods, using crosses between hardy wild cane species and rich tropical canes in the production of a series of varieties possessed of sufficient hardiness to grow in the rigorous, non-irrigated conditions of north India but possessed of a sugar yield distinctly higher than the canes that previously grew there, which have in consequence been entirely replaced by the new forms.

Polyploidy

An examination of the chromosomes of the new sugar canes reveals a very interesting state of affairs; they prove to be 'polyploid,' i.e. they contain not the original parental number of chromosomes but a multiple of it. This seems to be one of nature's favourite ways of restoring fertility in sterile interspecific hybrids. If we look once again at the sterile potato hybrid referred to above, with 60 chromosomes, and imagine what would happen if this number were to be doubled, we can at once see that every single chromosome would have a partner; that is to say, all 24 domestic chromosomes would have 24 other domestic chromosomes to pair with, and so also would all the 36 Mexican chromosomes. There would no longer be any difficulty in pairing and separation at the time of reproduction and the hybrid would probably be no longer sterile. This is what often happens in nature, and many cases are now known in which sterile interspecies hybrids have been restored to fertility in this way. One of the first of these hybrids to be obtained and to furnish an explanation of the phenomenon was *Primula Kewensis*, obtained at Kew in 1899 from the parents *P. verticillata* and *P. floribunda*. The hybrid was quite sterile and remained so until 1905, when seed was unexpectedly borne and gave rise to a perfectly fertile strain of *P. Kewensis* otherwise similar to the original one. This phenomenon was repeated in 1926 and was investigated by Newton and Pellew. These workers showed that both the parental species were diploid, with the somatic chromosome number 18, and the sterile hybrid was also found to have this number of chromosomes. Since

half these chromosomes in the hybrid had come from one species and the other half from the other species, pairing between them was impossible, owing to some incompatibility between the chromosomes of the different species. When, however, the fertile form and the fertile branch on the sterile plant were examined, these were found to have the double chromosome number 36. This duplication must have occurred during the division of one of the cells of the plant tissue, giving rise to a sector of the plant with the double number, from which the fertile branch arose. Plants of this kind, in which each chromosome of each parent is represented twice, are called 'amphidiploids.' Since the appearance of *P. Kewensis* similar cases have been repeatedly reported, and they have now been observed with such frequency and in such a variety of plants that their occurrence can no longer be said to be uncommon. Their great value is that they afford a means of producing fertile, true-breeding hybrids from species whose normal hybrid is sterile and completely useless from a practical standpoint.

The history of the wheat-rye hybrids in Russia affords an interesting and in many ways instructive example of which the details are not generally known. In 1918, natural hybrids between wheat and rye were observed in the fields at Saratov in considerable numbers, in the progeny of certain lines in particular. These favourable lines were therefore sown out in special beds intermixed with rye, and, in later years, a special method was devised of separating the hybrid grains from the ordinary selfed-wheat grains, by sifting the grains and sowing only the smallest, which proved to be the hybrids. The winter of 1924 was unusually severe and most of the wheat lines perished ; the hybrids, however, were more resistant and survived. In the following year, certain plants displaying an exceptionally high fertility were observed, these plants being characterised by large percentages of fertile pollen, normal flowering and normal grain formation. They were retained and carried on to the third and fourth generation where they retained their almost complete identity with the first generation hybrid.

That these plants represent a case of amphidiploidy was brought out by the cytological examination made of them. The reduced chromosome number in rye is 7, and in the bread wheat used as parent, 21. The fertile hybrids were found, however, to have 56 chromosomes, which represents the sum of the chromosomes of the parents multiplied by two.

These hybrids have displayed great resistance to cold and drought, together with many other valuable agricultural characteristics, and may be of much use in the future of Russian agriculture. Their significance is seen to be still greater, however, when it is taken into account that attempts had been made for many years in various countries to produce hybrids of wheat and rye of some agricultural value, and had almost invariably failed.

An equally interesting case is that of *Spartina Townsendii*, which first appeared in Southampton Water in the year 1870 and almost simultaneously at Le Havre in France. The new species spread with amazing rapidity in all places where it occurred and in a few years' time several thousand acres of it were growing and it had almost succeeded in exterminating the original species, *S. stricta*, the common cordgrass, growing there before the advent of the intruder. It was suggested on morphological grounds that the new species was a hybrid between the local species *S. stricta* and another species, *S. alterniflora*, which had been introduced some years previously from America and was growing side by side with *S. stricta*. This view was confirmed, moreover, showing the new species to be an amphidiploid with 126 chromosomes, exactly double the sum of the two supposed parental species *S. stricta* ($2n = 56$) and *S. alterniflora* ($2n = 70$).

This example illustrates how interspecific crossing may lead to the production of new species in nature and incidentally of how the new species may possess a higher selective value than the parental species, which are thus gradually exterminated. The conjecture naturally arises that this is a means whereby new species have arisen in the course of evolution. A concrete instance where such an assumption is definitely proved to be the case is provided by experiments on *Galeopsis*, the hemp-nettle. By crosses between the two diploid species *G. speciosa* and *G. pubescens*, Müntzing succeeded in producing a tetraploid form which proves identical in almost all respects with a tetraploid species already existing in nature, *G. Tetrahit*. The new form crosses with the natural species giving fertile hybrids, and there seems no doubt that by such means a naturally occurring Linnaean species has been recreated artificially, and, presumably, that this was how it originated in the first place.

Since then a number of other species existing in nature have been artificially synthesised in this way by crossing their supposed parental species and subsequent chromosome reduplication. An examination of the world's flora shows that a surprisingly large proportion of it consists of polyploids, many of which have arisen in some such way as that described above. In some zones the proportion of polyploid species is as high as 60 per cent.

and is often found to be specially high in regions with extremely rigorous climate such as arctic or desert zones. Sometimes the polyploid species has colonised new areas in which the original parent species have been hitherto absent and altogether there seems to be strong evidence that polyploid species that arise in this way are often endowed with properties of some sort—vigour or adaptability or some such quality—which enable them to survive where the species giving rise to them could not. This phenomenon has therefore attracted a great deal of attention from plant breeders, who have argued that if nature can produce plants with increased efficiency by hybridisation and chromosome duplication, why cannot we do the same? All the first amphidiploids known were found entirely by chance, but attempts were soon made to produce them artificially. If a means could be found, it was argued, to induce chromosome duplication at will, then interspecific crosses could be made in all directions and fertile hybrids of all combinations and kinds of species be made and the possibilities of plant breeding be enlarged beyond our wildest dreams. Why, there would be no end to the new combinations possible, and not only new combinations of existing species but new species themselves, not previously known to exist, could be created. But the hopes and fancies flew ahead faster than the concrete results and achievements. So far the much sought for method of inducing polyploidy had not been found. Various agencies were suggested for inducing polyploidy artificially. For instance, some plants when their tops are cut off form a wound callus on which buds are later formed, giving rise to new shoots. Many solanaceous plants such as nightshade, tomato, etc., do this. It was found that a surprisingly high proportion of these so-called regenerated shoots contained the double chromosome number, and fertile amphidiploid hybrids were formed artificially by applying this treatment to several sterile interspecific hybrids. The method, however, was limited in its application by the fact that not by any means all plants will regenerate in this way. The search for other methods was therefore continued.

Use of Chemicals

Heat treatment, cold treatment, centrifuging and many other agencies designed to give the plant a sudden shock were all tried, with varying success. In 1935 a Russian botanist succeeded in inducing polyploidy by the use of the pollinia of certain tropical orchids, suggesting a new line of approach, through chemical rather than physical agencies. Then in 1937 Blakeslee, in America, made the spectacular discovery that the old-fashioned drug colchicine, produced from the roots of *Colchicum autumnale*, the common autumn crocus, has the remarkable power of inhibiting the normal mechanism of cell division, in such a way that the chromosomes divide but do not separate into distinct cells. The result is the production of cells with double chromosome number. When the drug is removed the nucleus, now containing double the original number of chromosomes, divides normally, and a polyploid plant with the double chromosome number is obtained. Here at last was the long sought-for magic wand of the plant breeder for producing polyploids at will. The method was immediately applied to a wide range of plants and found to be very nearly infallible. It was taken up by plant breeders all the world over, and since that time reports have been published describing the artificial induction of polyploidy in this and that plant, emanating from almost every civilised country of the globe. Later other chemicals, such as acenaphthene, veratrine, sanguinarine and others, were found to have a similar effect; colchicine, however, still seems to retain pride of place. Its main use is in inducing fertility in otherwise sterile interspecific hybrids. An interesting example of its use is provided by a recent report from the Central Experiment Farms in Canada. In an attempt to secure large-seeded, vigorous-growing, drought-resistant perennial grasses for use as hay and pasture in the drier prairie areas, a great number of perennial grasses were crossed with wheat. The grasses used included the common couch grass, the familiar scourge of arable farm land, and two related species *Agropyron glaucum* and *A. elongatum*. The couch failed to cross, but seed was obtained from the crosses where the other two species featured. Some hundreds of thousands of crossed seeds were produced in this way but almost all the hybrid plants were sterile. This sterility was overcome by treatment with colchicine and now a sufficient quantity of seed has been procured for testing on a field scale. This is a clear case in which the use of colchicine has made possible the solution of an otherwise almost insoluble problem in plant breeding. This same method has been much used in latter years in the U.S.S.R.

But why, it may be argued, cannot the colchicine be applied direct to our cultivated plants and enable polyploid forms to be produced without the need for recourse to hybridisation. It is known that a large number of our cultivated plants are polyploid —take the wheats, the potatoes, the apples, pears, plums, raspberries, strawberries, to name only a few; would they not be still

further improved if their chromosome number were raised still further? This has indeed been tried. In this direction, however, the results have not been quite so promising as was anticipated. Tetraploids of flax, potato and certain other plants obtained in Sweden are inferior in yield or quality and many others produced elsewhere have proved either inferior or no better than the original, diploid parents. It would appear, in fact, that most plants have a certain chromosome number with which they most flourish and that increases beyond this number merely lead to deterioration. This number is known as the optimum number. It is moreover interesting to note that the majority of cultivated plants seem to be round about this optimum value already, so that improvement by further increasing the chromosome number is the exception rather than the rule. We must of course remember in this connection that very many cultivated plants are themselves polyploids and have probably reached the optimum level by a natural process of selection carried out in the course of centuries. Nevertheless improvements even along these lines have been registered: tetraploid cabbages, tomatoes and sugar beets have been found to be higher in sugar content, tetraploid mangels and sugar beets are less prone to bolting, and tetraploid plants of *Datura* have double the normal content of alkaloid, a feature which gives them a very considerable practical interest. Many tetraploid herbage plants characterised by higher yields of green fodder have also been produced recently in Sweden, and a further development is that tetraploid sugar beet when crossed with the original diploid, yields a triploid type which seems to have a higher sugar content than either. In exactly the same way, maximum vegetative vigour has been found in triploid forms of lucerne produced by the colchicine technique. The superiority of some of the artificially produced triploids makes it more interesting to consider the merits of some of the naturally occurring triploids among our cultivated plants. It is found upon examination, for example, that many of our best dessert apples and pears are triploids; there exists in South America a special, well-defined group of potatoes which are exceptionally frost hardy and are exclusively grown by the Indians for production of a dried frozen potato product known as 'chuño'; these varieties prove on examination to be triploids too.

The use of chemicals in inducing chromosome duplication and allied phenomena has recently received a further application which promises to be extremely interesting in connection with micro-organisms, especially yeasts. Tetraploid, hexaploid, octoploid and other polyploid yeasts have been obtained in Germany by treatment with compounds such as acenaphthene, α-naphthylamine and camphor. Camphor seems to be a specially active substance where yeast species are concerned, whilst colchicine had little or no effect. Some of the polyploid races were tested for their fermenting properties and found to differ in both the rate of fermentation and the quality of the product. One presumed tetraploid has been described as producing beer with a very fine flavour of the Pilsen type. Experiments in Great Britain with *Torulopsis utilis* yeast have also shown camphor to be very effective in producing giant strains, while colchicine and α-naphthylamine were found to be inactive. The giant strain retained its increased size during a year or more in culture and is thought to be of industrial value for the production of food yeasts both on account of its size and of its greater rate of multiplication. It has a higher content of nucleic acid but in all other respects was found to be identical with the original strain. Here would seem to be a most promising and fascinating new field open for investigation, especially in view of the therapeutic importance of many of the micro-organisms, such as *Penicillium*, at the present time. Genetic investigations are now being carried out with *Penicillium* species with the object of studying their drug-producing capacities, and many interesting results from such lines of investigation are to be foreseen. These investigations serve moreover to illustrate one of the most important trends in modern biological studies, namely the overlapping of different fields of investigation which hitherto have been regarded as quite separate and independent—in this case plant genetics and medicine. A further analogy with medicine is seen in recent observations of a group of English scientists who find that certain combinations of chemicals, each in itself relatively ineffective, may be exceedingly active in affecting nuclear division and inducing polyploidy, which discovery seems to open up still more new possibilities and fields for further development. It also illustrates another important modern trend in biological research: a growing appreciation of the significance of certain groups of chemical substances in influencing plant development and a realisation that simple chromosomal or nuclear relationships are not by any means the only deciding factors in determining this development. Considering first the important rôle of chemical substances, we may illustrate this by reference to another group of compounds, the so-called plant hormones or growth substances. That these exist and are responsible for many of the familiar phenomena such as the geotropic curvatures of stem and root, the phototropic

curvature of the stem and leaves towards the light, etc., has now been made amply clear. More recent investigations, however, seem to indicate that all growth processes are influenced by growth substances of one kind or another. A number of these substances have been discovered in coconut milk, which can be used as a culture medium for small embryos excised from the plant. Distinct substances have been identified in the coconut milk, one of which prevents root growth, causing the embryo to remain in an undeveloped condition; another of the substances causes proliferation of the cells and encourages cell division; another causes cell elongation, as opposed to proliferation. This last substance is the one which is responsible for controlling the growth of seedlings, stem curvature and many of the familiar phenomena of plant growth. It has actually proved to be a group of substances, referred to as *auxins*, which have maximum activity at a dilution of 1 in 4,000; the optimum concentrations, however, are different for roots and for shoots, and this accounts for the difference in the reaction of these organs. The typical function of the auxins is to control the growth of seedlings; without them no elongation takes place at all, and many of the effects of agencies such as X-rays, heat and light have now been shown to be the result of a diminution of the auxin content. Even ultra-short radio waves have been shown to reduce the auxin content of maize seedlings and hence reduce growth, which, however, was restored to normal when synthetic auxin was applied artificially.

These recent discoveries of the rôle of auxins in controlling plant growth have shed much light on the general problem of plant responses, but they have also added one further link in the chain of our knowledge of hereditary mechanisms, for certain typical genetical effects have been shown to be brought about by alterations in the auxin concentration. A dwarf form in maize has long been known as a typical example of a single Mendelian recessive character, occurring in the expected proportion of 1 dwarf : 3 normal in the second generation of a cross. The dwarf form, however, has lately been shown to be due to excessive obstruction of auxin in the tissues of the growing region. Another familiar genetic type in maize, known as 'lazy' is characterised by a prostrate habit, trailing along the ground instead of standing erect in the normal way; and this type has been shown to be lacking in the characteristic ability to move auxin when its position in space is changed and is in consequence of this incapable of producing the normal geotropic curvatures, and this is why its stems never become erect.

Here then is a purely chemical explanation of two typical genetic phenomena, since the chemical formula of the auxins is now well established and they can even be synthesised artificially in the laboratory. Moreover, effects similar to those of the auxins have been produced by a number of other synthetic chemical compounds not known to occur naturally in plants. The same is true of many of the so-called vitamins, which can now be synthesised in the laboratory and many of which, moreover, have been classified as plant hormones. Some very interesting researches have been carried out with this group of substances in America. Strains of a certain fungus, *Neurospora* by name, have been found which are unable to synthesise certain chemical substances which the normal strain forms in the course of its development. The substances in question include a number of the common vitamins such as thiamine, nicotinic acid, thiazole and many others, some as yet unidentified. The deficient strains usually differ from the normal in a single Mendelian gene and react quantitatively to the addition of the substance artificially to their culture medium, just as they would to the addition of a hormone or growth substance.

The picture we see before us therefore is rather kaleidoscopic—we see the lines of demarcation between various groups of substances or phenomena, formerly so distinct, gradually becoming less defined or even disappearing altogether. The bodies concerned up to now are seen to include the genes, or Mendelian units of heredity, the hormones, or substances regulating plant and animal growth, the vitamins, or accessory food factors, and many synthetic chemicals. To this list we may now add enzymes, the familiar catalysts in most biochemical changes, since there is now evidence that auxin acts as a catalyst or co-enzyme in the respiration system. This in itself is a pretty imposing list of barriers broken down; but the process does not end here. We now learn that many of the symptoms characteristic of virus diseases may also be produced by other means. A group of workers in the U.S.A. have shown the most striking parallels between plant viruses of varying degrees of virulence or invasiveness and certain types of variegation contolled by the plastids, which are normal inclusions of the cell cytoplasm independent of the nuclear apparatus. These variegations can be arranged in a series, depending on the extent to which the plastid structure and function are modified, and each member of the series shows a more pronounced resemblance to certain virus diseases. A further resemblance to virus diseases is that some of these variegations can be transmitted

by grafting, and the more abnormal types would seem to be more invasive than the less extreme types. Thus, for instance, the vein-yellowing variegation of *Lonicera japonica*, *L. brachypoda reticulata* Nichols of horticulture, was transmitted to several green varieties of *L. japonica*, and other similar cases have been recorded. From their now extensive observations on this new subject the American investigators have drawn the interesting conclusion that 'certain viruses may be considered as derivatives of the chromosome, which have become modified through evolution, rather than as derivatives of parasitic micro-organisms.' Their arguments have been supported from the chemical side, since it has been shown that the plastids or pigment-bearing bodies of the cells can be broken down by controlled chemical treatments. First of all they remove the green pigments or chlorophylls, then the yellow carotenoids, and then the egg-yolk or lecithin-like components, and finally what are they left with? A protein of a special type found characteristically in cell chromosomes and known as a nucleoprotein, which curiously enough proves to be similar to the nucleoprotein found in the viruses, if not identical with it. So once again, it would appear, the chemist and not the biologist is to have the last word.

The chemical approach to the concept of the gene or unit of inheritance has also produced much food for thought on that interesting and much discussed topic, the nature of the gene. Evidence had been accumulating for some time to show that the strict Mendelian interpretation of heredity in terms of unit characters is not by any means the whole story. More and more cases have come to the notice of geneticists in which a clear-cut segregation of the progenies into the expected mathematical proportions does not occur; many exceptions appear. Some of these exceptions are, moreover, as so often occurs in science, themselves very instructive. In the past the chromosome has been considered as a mere vehicle, along which the genes were arranged one by one like beads on a thread; the constitution of these beads was held to be the important consideration and their actual arrangement along the thread thought to be immaterial. It now seems, however, that the serial pattern of the chromosome and the genes contained in it is important as well as the particular qualities of the genes themselves. This view has received the strongest support from the distinguished geneticist and experimenter, Richard Goldschmidt, who points out that chromosome breaks which lead to new serial arrangements of the parts of the chromosome, without any actual gain or loss of chromosome material, may produce definite genetic effects. Much evidence has been adduced by Goldschmidt to show that this effect 'has nothing to do with the theoretical units, the genes, but is an independent effect of the whole chromosome or of more or less small sections of it.' Once again the explanation is offered in terms of chemistry. It is pointed out that in chemistry, especially organic chemistry, it is not at all rare among the rather more complex groups of substances to find that two quite distinct compounds, with entirely different chemical properties, may prove to have the same composition as regards the total number of atoms of carbon, nitrogen, oxygen and so forth contained in the molecule. The only difference is in the exact spatial arrangement of the atoms in the molecule. Thus glucose, to take a crude example, in solution deflects transmitted light to the right, and fructose, which has exactly the same atoms in the molecule but in the opposite positions, as in a mirror image, deflects light to the left and has certain other properties too, which distinguish it from glucose. Other compounds might be cited, where the difference is somewhat more complicated as regards the actual position of the atoms with relation to one another in the molecule. Such compounds, differing only in the spatial arrangement of their atoms, are known as 'stereoisomeres.' A particularly interesting case is the male sex hormone in animals, which is responsible for the familiar differences between the male and female of a given species. This compound has a number of stereoisomeres, all differing in the precise nature of the effects they produce, and some of them have no physiological effect at all.

Now many of the effects of compounds such as the sex hormone just discussed bear, as has been already pointed out, a close resemblance to the effect of many so-called genes in inheritance studies. It has been suggested therefore by Goldschmidt and others, that the genes themselves may have no real existence at all but only represent differences in pattern arrangement of the elements in some enormous molecule. If, moreover, we identify the chromosome itself as this enormous molecule, the explanation of many genetic phenomena becomes extremely simple. The phenomenon of 'mutation,' for instance, is one of the most typical genetic effects: a strain of plants or animals which has bred true for a particular character for generation after generation suddenly throws an off-type, a so-called sport, known to geneticists as a 'mutant.' Mutants have been found in almost all animals and plants, also in the fungi, bacteria and viruses as well as in the plastids, which, as we have seen, have many other properties in common with

viruses. The chromosome-molecule hypothesis makes the explanation of mutants quite simple : a slight change has occurred in the arrangement of the elements within the chromosome, or in other words a stereoisomere has been produced, with slightly different properties from the original compound. Many mutations are reversible, the old arrangement presumably having been restored ; some, however, are never restored, and in such cases it is justifiable to suppose that some small portion of the chromosome or molecule may have been irretrievably lost. Mutants of this type are often produced by the effects of external agencies such as X-rays and are more often than not inferior in some respect or other to the original unmutated strain. Several cases are now on record in which a known mutant of this kind, recognisable genetically, has been traced to some definite portion of a chromosome, which can be visibly identified.

This view of the chromosome as one enormous molecule with the genes arranged along it in side chains may be an undue simplification but it is an exceedingly compelling analogy and offers the simplest explanation for many phenomena. A regrouping of the chromosome constituents may produce some quite simple change which, acting in the early developmental stages of the organism, has such fundamental consequences that it alters the course of development of the whole organism. Many of the differences between genera or higher orders, or between male and female of the same species, are of just such a type as this. Such a change leads at once to a new type which will be immediately subject to natural selection, and thus at least one feasible mechanism for the origin of species is suggested in which it is unnecessary to assume the existence of the so-called ' missing links ' or other improbable assumptions commonly made by geneticists engaged in evolutionary speculations.

Non-Mendelian Inheritance

The concept of the 'chromosome-molecule' may perhaps serve as an explanation for certain other phenomena which have been baffling geneticists for some time. In latter years more and more instances have been reported of characters whose inheritance does not follow the accepted rules of Mendelian segregation. These have been roughly classed together as ' non-Mendelian inheritance ' and have not received much attention until recently, when a number of Russian scientists have laid much emphasis upon them. This Russian school takes its ideas mainly from T. D. Lysenko, the well-known originator of the principle of vernalisation. According to Lysenko's theory plant growth and plant development are two distinct and separate phenomena, each of which is capable of proceeding independently of the other. Development is supposed to take place in stages, each stage requiring a particular combination of environmental factors, which may be different for different stages. Some of these factors are only required for one particular developmental stage and when this stage is completed they can be dispensed with altogether. The importance of the distinction between growth and development is that if the factors required for the completion of each developmental stage are known and can be provided for the requisite lengths of time, all the stages leading up to reproduction can be effected at any desired time, even in a freshly germinated seedling, without any growth taking place at all. The seedling can then be planted out and will proceed with its growth, and, the developmental stages all having been completed, it will proceed also to reproduction without any delay and rapidly produce seeds. By the application of this principle Lysenko claims to have made it possible to grow crops in very large tracts that were previously unsuitable for cultivation owing to their having too short a growing season. From this Lysenko proceeded to hybridise forms which were late in maturity owing to a delay in one phase with forms delayed in another phase and so produced early maturing hybrids. Next he subjected winter wheat plants to partial vernalisation and found that the progeny behaved mainly as spring forms, from which he argued that by suitable ' training ' the hereditary nature of a plant or animal could be radically changed without recourse to hybridisation. Other instances of this were quoted from the work of the now famous Russian fruit breeder, the late I. V. Michurin, who, among other things, advocated the method of ' mentors,' which consisted of grafting on to a young hybrid in its early growth stages a scion of an old-established variety, whereby it was claimed that the hybrid acquired many of the desirable characters of the old variety. Finally great importance is attached by the Michurin-Lysenko school to ' vegetative hybrids.' Most so-called vegetative hybrids described in the past, such as the famous *Crataegomespilus* and *Cytisus Adami*, have later been shown to be chimaeras, consisting of mixed tissues which have undergone no nuclear union, but the Russian school refer to the work of Darwin and bring forth a large body of new evidence from which they confidently affirm that vegetative hybrids can not only be produced but behave in inheritance in exactly the same way as true sexual hybrids. All this leads the Russians to conclude that

the hereditary constitution of a plant or animal is not fixed, as supposed by geneticists, but is subject to modification under the direct influence of the environment, in much the way that was assumed by Darwin in formulating his theory of the origin of species. Now the difference between the two schools of thought is fundamental: the orthodox geneticists believe that the 'genes' and all that goes with them, are unchangeable except by some profound process known as mutation, which occurs at random and is not capable of being regulated or directed by man. The Russian school, on the other hand, believe that no difference exists between the reproductive tissue and the ordinary body tissue and that any changes exerted on the latter by environmental influences are transmitted to the offspring, and moreover they believe that these changes can be directed and controlled and made to go in whatever direction the experimenter desires. One of the experiments quoted as giving evidence for this view was made by A. A. Avakjan, who grafted a leaf of a tomato variety with entire leaflets on to the variety 'Albino,' which has dissected leaflets. Seeds taken from a fruit formed on the Albino variety gave rise to a number of plants with entire leaflets. This is ascribed to interchange of nutrient substances between the cells of the scion and stock, which finally affected the constitution of the embryo cells and hence the seedlings.

An embryo is compared to a spiral, formed by the developmental process of the generation which gave rise to it. The development of the new generation is likened to the unwinding of the spiral, which consists in the development of the potentialities of the initial cell. The initial cell of an organism is the most complex, and succeeding generations of cells become less complex, losing some of their potentialities. Thus from a sex cell or a group of cells in the eye of a potato a whole organism may develop, but from leaf cells in many plants this is not possible. The manner in which this differentiation takes place depends on the environmental conditions—e.g. plastids become green only in the presence of light. Young varieties of fruit trees, which have not yet completed their formative processes, are held to be more susceptible of influence by grafting on to different rootstock varieties than old-established varieties. When these young varieties, which are described as being phasically immature, are grafted, they usually alter the whole course of their further development and give rise to mature plants quite different from those produced on their own roots.

When seeds are taken from fruits developing on the stock and scion of such grafts, plants are obtained which possess properties characteristic of both partners. This occurs in spite of the fact that neither chromosomes nor protoplasm have been interchanged between the partners, the interchange being confined to materials transmitted in the sap. These materials are therefore capable, it is concluded, of transmitting the properties of the race—i.e. its hereditary constitution. This again brings the Russian school into strong conflict with geneticists elsewhere, who maintain that effects of this kind, though they can certainly be obtained, are not transmitted to the progeny of the affected individual, whereas according to Lysenko they are. He cites a number of experiments with tomatoes in which, for instance, a white-fruited variety is grafted on to a red-fruited variety and its fruits develop varying degrees of red coloration. The seeds are saved from these fruits and are sown the following season. Many of the plants so obtained, it is claimed, bear red fruits and progenies obtained in this way are said to behave in just the same way as hybrids obtained through the normal process of pollination and fertilisation. It is also claimed that growth habit, leaf form, length of vegetative period, size of fruit and many other characters, have been transmitted by vegetative hybridisation in the same way, though it is admitted that in certain cases the effect is not observed. The tomato 'Best of All,' when grafted on to black nightshade, was altered in every single character and some of the plants produced offspring with very much improved fruit flavour. Forms distinguished by greater earliness were also obtained in these ways, some of them maturing earlier than any known cultivated tomato. The Russian investigators further maintain that effects such as those described are obtained with more certainty if the upper partner of the graft, i.e. the one whose characters it is desired to change, is taken from a young seedling with its leaves removed, while the lower partner should comprise an older, fully mature plant in the full vigour of development; it should moreover be allowed to retain as many of its leaves as possible. In this way, they say, the experimenter succeeds in 'inducing the scion to assimilate the maximum amount of the substances elaborated by the stock and to overcome its antipathy to them.' The now famous Russian fruit breeder, I. V. Michurin, based all his work on the above principle, which he styled the method of the 'mentor,' since the mature variety serving as rootstock served to guide the inexperienced young seedling and induce it to develop in a given direction. It is apparently necessary sometimes to exert these influences over two or more successive generations before the desired effect is obtained. Seedlings obtained from crossing two parents

differing widely botanically, such as peach and almond, or in place of origin, such as American × Chinese plum species, are said to be more susceptible of being influenced in this way, since their hereditary constitution has been 'shattered' by the process of crossing such widely different forms. Sometimes the two parent species which Michurin wished to cross were mutually incompatible and refused to cross at all. This incompatibility was overcome by a variety of different treatments designed to bring about a physiological exchange between the two partners. One of the most frequently used methods was that referred to as 'vegetative *rapprochement*,' whereby the two partners were grafted on to each other and left in vegetative union for a space of time, after which their flowers were inter-pollinated. Species which in the first place were quite incompatible were often crossed successfully by this means. Another method was to pollinate one species with a mixture of pollen from a number of different varieties of other species or even with a mixture of pollen from a number of different species. This enables the plant to exert what is referred to as its selective capacity, those pollen grains with which the plant in question feels itself most in agreement being selected for fertilisation. This again is held to illustrate the fact that fertilisation is a peculiar process of assimilation, a view which is also supported by reference to the phenomena of cross-pollination. These Russian investigators strongly uphold the Darwinian viewpoint that crossing leads to invigoration and inbreeding or close breeding leads to degeneration. Lysenko for instance writes: 'The normal vital contradictions, the vital impulse is created, and is periodically renewed in the plant and animal kingdom in the vast majority of cases by crossing, by fertilisation, by the sexual union of plant or animal forms which differ even slightly between themselves.' 'The fertilised egg cell contains all the inherent properties of both parents and from the contradictions that exist between them there arises an internal vital energy, which is the property of being able to change and be transformed.' In pursuance of this principle, crossing has been practised not only between species and between varieties but also between individual plants within an agricultural variety which judging on mere morphological standards was homogeneous. Quite material improvements in both yielding capacity and in quality and other features have been claimed from this procedure. The method at first consisted of emasculating one set of plants, i.e. removing the anthers or male organs, and pollinating them artificially with pollen collected from another plant of the same variety or with a mixture of pollen from a number of different plants. This somewhat laborious procedure has now apparently been replaced by the simpler method of emasculating one set of plants and leaving them free to be pollinated by any plants that may happen to be growing in their vicinity in the field; in this way their capacity for selective fertilisation is exercised to the full. The method was in fact first called by Lysenko 'marriage for love,' but this designation seems to have been dropped in the more recent Russian literature on the subject. From such treatment increased hardiness as well as improved yield has been reported, even in the variety known as Lutescens 0329, which was hitherto the hardiest variety available; the improvement in hardiness cannot therefore be explained simply by assuming that it had crossed with some hardier variety. Fertilisation is regarded as a process of mutual assimilation or absorption by the two sex cells; the degree of expression of the paternal and maternal characters depends in the first place upon which of the two cells is the more active in absorbing the other, but in the second place it depends also on the treatment which the developing hybrid receives during its early life. The young hybrid, Lysenko says, is in a particularly malleable condition owing to its having its hereditary conservatism shattered by the process of crossing. It can thus be moulded in a given direction, and by a judicious choice of environmental conditions over a number of successive generations it is thought possible to bring about successive improvements in a given race of plants or animals. 'The hereditary constitution,' Lysenko says, 'is a concentrate of the environmental conditions assimilated by the plant organisms in a number of preceding generations. By means of skilful hybridisation, and by sexually uniting two races, all the matter that has been concentrated, assimilated and transmuted from dead to living during a period of many generations can be combined into one organism.'

It will be seen from what has been said above that many of these modern Russian views on heredity are in strong conflict with the views held in other parts of the world. It will also be seen, however, that the views of geneticists all over the world are gradually beginning to change, so that many of the principles which a few years ago were regarded as immutable laws are now seen to be at the best either mere approximations or undue generalisations. The Russian views call for a careful re-examination by impartial and independent observers; so do the accepted views on the laws of inheritance. There seems every reason to suppose that when these two apparently conflicting viewpoints have been subjected to such a critical

and impartial re-examination, each will be found to require a certain modification ; and it is not improbable that when these modifications have been effected, the two schools of thought will be found to have a great deal of common ground and not be in such violent conflict as they are at present. It is only by such processes of periodic re-examination and subsequent modification that science is able to progress, and many is the time in the history of science when from two apparently opposing viewpoints some new truth, incorporating the elements of both, has emerged and provided the starting point for further advances. It is much to be hoped that this will be the case in the so-called ' genetics controversy ' which has raged now for several years, both within the U.S.S.R. and outside its borders, and that ultimately a new set of principles will be arrived at which will explain the phenomena of inheritance to the satisfaction of both schools.

SCIENCE IN BUILDING

By Dr. J. L. Martin

I.

What is the Place of Science in Building ?

If there had not been misconceptions about the place of Science in building it would hardly be necessary to discuss the question here, or to attempt to bring these subjects into the simple and easy relationship which they once enjoyed. Their intimate relationship is, in fact, a matter of history that goes back to the beginnings of civilisation. It is early building that shows most clearly the development of the early sciences of measurement and geometry in just the same way that other practical arts, pottery, metal work and weaving provide the rudimentary beginnings of chemistry, physics and mechanics.

But it is misleading to over-simplify the problem. The historical relationship between science and building is one of complicated interactions. Science and building are activities which may arise from each other, may prompt each other, but in the main have developed in complete independence and isolation. It is, for instance, a plain historical fact that building, throughout the greater part of its history, adopts empirical methods—the rule of thumb methods of the craftsman—and, although it may involve scientific principles, it cannot necessarily be said to be guided and informed by them. It is one thing to follow scientific laws proved on the basis of practical experiment. But it is quite another to discover those laws and to formulate them into explicit theory so that they can be consciously applied, and it is not until this process starts that we can talk about the application of science to building.[1]

The actual formation of the scientific principles of building is a study that has been steadily built up in the last three centuries and rapidly expanded in our own. The beginnings of this study are to be found in such work as Leonardo's investigation of the behaviour of materials under stress, Galileo's geometric proof of the strength of beams, Derand's study of arch abutments, the experimental tests of Hooke and Blondel, and Wren's speculations in structural mechanics. Developments of this kind in the seventeenth century were continued and extended in the eighteenth, from experimental and also mathematical angles. At the turn of the century, in addition to materials and structural mechanics, such problems as heating, lighting and ventilation had come within the range of scientific investigation, particularly by Count Rumford. With Rumford, indeed, there was no artificial separation of theory and practice. His wide knowledge of the provision of warmth was carried through to the practical construction of stoves. He not only measured the efficiency of lamps but also designed them. He improved the comfort of rooms by his fireplace which did not smoke.

So far as the supporters of this scientific approach are concerned there is no doubt of their intention to apply their new knowledge to practical ends. The Paris Academy of Sciences, for a number of years after 1761, published descriptions of the improvement of the useful arts by the application of science. When Rumford founded the Royal Institution in 1799, it was with the specific object of diffusing ' the knowledge and facilitating the general and speedy introduction of new and useful mechanical inventions . . . and teaching the application of the new discoveries of science to the improvement of arts and manufacture and to the increase of domestic comfort and convenience.' Only a few years earlier, in 1794, the Ecole Polytechnique had inaugurated a course of training in applied mechanics, and its theoretical courses were without doubt the main reason for the advanced constructional skill of French designers.

During the course of the nineteenth century, the new knowledge was having its effect

both on the methods and on the materials of building, and was receiving practical shape in iron and, later, steel structures which not merely increased the scope of building but also revolutionised its formal effects.[2] In England, Bessemer's converters transformed iron and steel production, by the use of science, from process of hand forging to one of mass production. They made available in quantity and at moderate cost a material with a strength well beyond that of any traditional material both in tension and compression. With this material of reasonably consistent properties, and before long of standardised sections, the main supporting framework to any building could be exactly calculated. Thus the use of a new material, developed by science, makes possible a further use of science in the design of the building structure itself.

With the introduction of iron and steel construction, scientific method had, in fact, replaced traditional craft method in an important structural element. The large span structure—such as the great steel and glass roofs of railway termini and the famous *Galeries des Machines* of the French exhibitions—becomes possible. The way is open to the complete steel framework of the modern building, which in turn will require new advances such as the reduction of weight in floors and walls, the development of fire-resisting forms of construction, and the introduction of the lift. Side by side with these structural developments, there is a steady improvement in methods of lighting buildings, and providing them with warmth. At the beginning of the century, Murdoch had introduced the use of gas into buildings—eighty years later Newcastle had been given a first demonstration of electric lighting by Sir William Swan. But this new brilliance, though perhaps more startling, is not more far-reaching in its effects than such fundamental investigations as those of Leslie which established the principle of radiant heat and laid the foundations for subsequent advances in the provision of warmth.[3]

These are important changes that can be attributed directly to science. Its influence shows itself again in the rapid improvement of Portland Cement, culminating in the chemical discovery of aluminous cement in 1913 and the formulation of the general theory which made possible a combination of steel and concrete (reinforced concrete) and gave to building a second major structural advance. The debt to science in this case has been acknowledged by the engineer, Sir Owen Williams, who has remarked that reinforced concrete was born of the brains of mathematicians and physicists.

But, although the scientific basis of steel and reinforced concrete work is commonly accepted, it is not generally realised that to limit the effects of science to these engineering aspects of building is entirely arbitrary. It is, of course, obvious that the advances made by the engineering sciences are of a major character and perhaps considerable enough to require specialist treatment. But they cannot be isolated from the development of building as a whole. What we see in the introduction of scientific method into certain structural systems is at bottom only the first stage of a great transitional development through which building itself is now passing. It is but one aspect of the evolution by means of which a widespread and traditional industry is slowly and painfully changing its methods.

The general trend of this change can only be observed by considering the development of the building industry in all its phases over a period of time. If this is done it is an inescapable fact that in both materials and methods the traditional craft approach is being replaced. Materials and components are being produced more and more under scientifically guided conditions, and the empirical knowledge of the building craftsman is being steadily replaced by scientific knowledge.

Up to the present time, it is particularly through the structural sciences and the chemistry of building materials that science has found its way into building. There remains much to be done in these directions, but the development of scientific research, particularly in the past few years, makes it certain that we can expect changes in building of incomparably greater importance than we have yet seen. Science has developed and is still developing the answer to how we shall build and what materials and methods we might use. But it is now also turning to the far more fundamental question of the environment that human beings require for health and comfort. It is, therefore, providing the answer to two questions. The first of these is *how we shall build.* The second is the more far-reaching issue of *what we require from buildings,* and it is clear that this is the question to which we must first give attention.

II

What do we Require from Buildings?

(Comfort and Amenity)

If we ask the question—What do we require from buildings?—the answer appears to be simple. We need those conditions which lead to comfort and health. These are, reasonable access of sunlight, effective day-

light, adequate standards of warmth and freedom from disturbing noise. It seems, indeed, that these requirements should be easily obtainable.

But, if we consider the towns in which a great proportion of the people of this country spend their lives, it becomes clear that the provision of these necessities is neither so simple nor the prospect so reassuring as one might expect. The town, as it presents itself in aerial photographs, is a densely built-up area in which the streets appear as a pattern of cracks and fissures. Across these fissures are cast the shadows which darken the adjacent buildings. Along their lengths echo the street noises that have become more widespread during the past half century. In providing the warmth within buildings we send out from them the concentration of gases, liquids and solids which form atmospheric pollution.

Thus, by the manner in which we have developed towns, we have in many ways created artificial conditions. These conditions prevent the enjoyment of the simple necessities of sunlight, air and quiet, which are the natural amenities of rural surroundings. In some parts of London, for instance, the atmospheric pollution falls back upon the town in the form of grit at an average monthly rate of 20 tons to the square mile or hangs about in the form of smoke in concentrations as dense as one ton to the square mile. This results in an increased rate of failure of metals and paint surfaces, and a general deterioration of the fabric of buildings, in addition to increased costs of cleaning, redecoration and laundry. It is estimated that the nation suffers an annual loss of over £25,000,000 in this way. This is quite apart from the effect on general health. Two scientific workers in an industrial town some years ago measured the effect of smoke concentrations on daylight and found that quite 40 per cent. of the natural lighting was being excluded. They showed the devitalizing effect of this loss of ultra-violet light and of soot deposit on plant life. Medical research has carried this study still further by observing the corrrespondence between atmospheric pollution and ill-health.[4]

These conditions of atmospheric pollution arise directly from industrial plant and domestic fires. In providing the power and warmth by which people work and live, the sunlight and daylight which they need for general health have been reduced. There is clearly a case for an investigation of the provision of warmth on these grounds alone. But there are other important reasons for such a study. The standard of warmth in housing in this country is less than is generally desirable and certainly less than that provided in housing in Germany and America before the War.[5] Nevertheless Germany produced this improved standard of warmth with a fuel consumption which was less per head than that of Great Britain. This evidence of waste in the production of warmth can be confirmed in other ways. Recent investigations have shown that the average annual consumption of coal is 1·21 tons per head of population but that a much improved standard of warmth, hot water and heat for cooking is possible from not more than 1 ton of coal per head.

An effective study of the way in which warmth is provided in buildings could improve comfort and prevent great wastages. It might reduce, for example, the waste involved in atmospheric pollution. This in itself would result in increased sunlight and daylight. But in addition we now know as a result of scientific study the most desirable spacing and siting to secure the maximum advantages of natural lighting. This spacing and grouping for advantages of lighting might in turn have repercussions on heating—for example, the additional warmth from increased sunlight may reduce the amount of internal heat required within the building itself. The way in which buildings are spaced can also have an important bearing on noise reduction.

In short, these problems of providing the desirable comfort conditions within the town are interrelated. They react on each other. Towns can be developed in such a way that conditions of lighting, pollution and noise will become progressively worse. This is in fact what is happening to-day. But it is only necessary to be aware of the scientific knowledge available to see how this harmful development can be stopped and given a new orientation. The opportunity is there. Even if there were not large bomb-damaged areas to be reconstructed and large-scale housing projects, towns are themselves always being changed and rebuilt. Such rebuilding can be done in a haphazard and piecemeal fashion or it can follow a policy planned to secure the greatest advantages of comfort, convenience and health for the people and a general improvement in the elegance and dignity of their urban surroundings. To do this it will be necessary to use the knowledge made available by a great body of scientific workers in many fields, who have contributed to the study of such problems as warmth, daylighting and sound transmission, and whose work is drawn upon in compiling the following notes.

(*a*) *Warmth and Comfort*

To tackle the problem of warmth it is necessary to know first of all what are the

most desirable indoor conditions for general comfort, and this whole question has been summarised in a recent paper by Sir Alfred Egerton.[5] At the outset we are confronted with the difficult question of individual feeling of comfort and the changing reactions of the human body to various types of environment and activity, and only a combined attack on physiological as well as physical grounds can produce effective results. Joint action bearing on this and the subjects of mutual interest has in fact for some years now been undertaken by the Medical Research Council and the Department of Scientific and Industrial Research.

The human body maintains its even temperature by giving off heat. Physiologists have shown the rate at which this heat is given off for varying activities and the average heat-loss for varying occupations can be calculated. Within buildings, factors which affect this radiation of heat from the body (and therefore human comfort) are air temperature, radiation from warm fires or cool wall surfaces, the flow (and to a certain extent the humidity) of the surrounding air. Different air temperatures, different degrees of radiation from surroundings and different rates of air-flow may give equal results from the point of view of comfort.

The ordinary thermometer designed for recording air or liquid temperature only is therefore an unreliable guide to comfort conditions. But a Building Research Station worker, Mr. A. F. Dufton, was able to devise an instrument which could record all the necessary measurements. The instrument used was provided with a surface temperature approximately the same as the surface temperature of clothing on the human body. By recording the amount of heat required to maintain this surface temperature in a given environment it was possible to obtain an index of the rate of cooling of the surface—and thus to have a measure also of the effect of environment on the clothed human body.

This measure (known as ' equivalent temperature ') [6] was later shown after a great many tests of individual reactions to environment to give a reasonable indication of the average comfort sensations. It is, naturally, impossible to define individual reactions and needs, but it is possible to give in broad terms the desirable warmth standards for the majority. Standards of warmth in buildings must take into account the way in which rooms are used and make suitable allowances for sedentary and active occupations. They must also take into consideration the desirable ventilation.[7]

As excessive ventilation can only lead to waste of heat the principal aim in laying down standards is clearly to suggest the minimum ventilation required.[8] If we assess the oxygen needed and the carbon dioxide expired in normal breathing it can be shown that ventilation will not generally be required for the renewal of oxygen content of the air in a room. A much stronger reason for the introduction of fresh air would be the effect of this in eliminating micro-organisms such as those which carry the common cold. To do this at all thoroughly, however, would require nothing less than a succession of draughts which are undesirable for other reasons. By far the most reasonable minimum standard for ventilation seems to be that which will remove odour. The extent of ventilation necessary for this purpose has been the subject of American experiment, and the figures available allow the right degree of ventilation to be carefully related to heat requirement without any risk of waste.

Standards of warmth which take all these factors of comfort, ventilation, etc., into consideration are now available as a guide for future building work.[9] It is unnecessary to list them here, but it may be said, in passing, that they provide an improvement on the existing standards available in most houses. In housing, for example, it is suggested that no part of the house should be left completely unwarmed. This would be achieved by the provision of a slight amount of general heat which would prevent the temperature from dropping at any time below 50° F. The effect of this would be that condensation inside houses would rarely occur, and the moisture which in unheated rooms is absorbed by bedding and settles on furniture under certain climatic conditions would be eliminated.

With these standards laid down, the exact amount of heat required for adequate warmth and comfort can be accurately assessed. The data that are used draw largely upon the scientific work of the Building Research Station. It is possible in the first place, using their method of assessment, to take account of the varying climatic conditions in any part of the country. Then, by using their knowledge of the thermal properties of floors, walls and roofs, the heat needed for various forms of building can be ascertained.

The heat that is needed depends very largely on structural method, and if this factor were always taken into account major economies of fuel might be made. Many forms of construction offer plenty of scope for improvement. Heat is constantly being wasted through the structure itself. A recent report on 'House Construction' in emphasising this point shows that the annual heat-loss through the normal timber floor used

in house construction costs as much as 1·7*d.* for every square foot of floor. The same report shows that this loss could be halved without difficulty, without any cost increase, and with benefits to the occupier and the nation. Not only floors, but the walls and roofs of normal houses are below the desirable level of performance, and capital expenditure on additional insulation could be readily justified in annual savings in fuel consumption.[10]

Once the heat required is known, the final problem of warmth is how to supply it in the most efficient manner. Allowance has to be made for washing and hot water supply. It is also necessary to study the most suitable appliances and fuels and the scale on which warmth can be most economically supplied. The provision of heat 'on tap' like water must be considered whether this is by gas or electricity which exist, or by the development of a centralised supply of hot water or steam heating to whole communities. This development which is known as district heating has yet to be worked out effectively in this country, although its use on a modified scale in war-time building schemes and extensively as town heating in Russia, Germany and America gives promise of great economies.

One further consideration in the choice of method is the reduction of atmospheric pollution which might be obtained. Effective results can be obtained even in individual houses. But if centralised sources of heat are extensively developed the problem becomes simpler. One plant working under controlled conditions replaces numerous sources of pollution such as domestic fires and individual heating boilers. This centralisation of plant might allow the use of smokeless fuels, or the washing of fuel and treatment of flue gases before they are emitted from the chimney as is sometimes done in large industrial plants.

These general notes cover a field which has been very closely investigated. With the support of these investigations it will be seen that there are available the data to enable the provision of warmth to be accurately assessed and scientifically provided if we care to use them. This would affect the public in two ways, first by its direct repercussions on their comfort, surroundings and environment, and secondly on a national scale in so far as it secures the most effective use of national resources. A comprehensive investigation of the provision of warmth on a national scale would cut the wastage that is going on by considerable proportions. If this study covered the subject of by-products such as fertilisers, plastics, and dyes the net economy would be still more important: and as the cost of fuel burnt annually in this country is approximately equal to the cost of building some 200,000 to 300,000 houses, this whole question obviously calls for immediate attention.

(*b*) *Daylight and Sunlight and Artificial Illumination*

It is a sad commentary on our methods of town building to find that so much of the technique of studying daylight has been built up around actual failures of daylighting and claims for 'right of light.' Daylighting is, of course, affected by obstruction and consequently is intimately linked to siting and planning. The regulations which govern daylighting in town development, however, do no more than limit the *heights* of buildings. The development of the town takes the form of an increased density of buildings in relation to site area. The street frontages are maintained but building heights have increased. So long as new buildings are confined within a line that relates their height to the street width, they can be built.

How completely this development has been outstripped by scientific study has been shown in recent studies by the Building Research Station.[11] The study of daylighting in relation to planning has been developed by graphical and mathematical methods. If we take an area of site for example, a certain number of people could be housed on it in parallel rows of two-storey buildings. Now if we take the *same number* of people and house them in five-storey buildings not only will the building blocks enjoy better daylight, but the free site area will be *increased* per head of population. This improvement and increased ratio of open space goes on with each increase of height although at a certain point no further advantage can be gained. To quote actual figures: if the distance between three-storey blocks is double their own height, the corresponding distance between ten-storey blocks is equal to three times the height of the blocks. The free space *per inhabitant* around the ten-storey blocks is nearly twice as great as it would be if three-storey blocks were used.[12]

From the point of view of urban planning this shows that there is a close relationship and interdependence between daylighting, density of population and site area. More recent work by the Building Research Station has shown the possibility of alternative types of layout to improve on the lighting obtained by parallel rows of buildings. If in these rows, for example, every alternate building were placed at right angles to the row some advantage of daylighting would be gained from the broken skyline. Most urban building takes the form of rectangular sites bounded by buildings surrounding a light

area—it is, in other words, based on a hollow square type of plan. If the area of floor space of such a building is arranged on the same site in the cruciform or Y shape it can be shown that the daylight is very considerably improved.[13]

As a result of these new daylight studies we now see that it is perfectly possible to obtain adequate daylight on ground-floor rooms in developments which have a density of population as great as, or even greater than, those now customary in the central districts of great cities. But this will never be possible—in fact, nothing but the hollow square type of plan is possible—unless the land is developed in large areas.

All this is equal to saying that the normal urban development from the point of view of daylight (and almost certainly of sunlight, noise and open space too) is well below the level that it might reach with a rational development of sites. So long as piecemeal development of sites continues the wrong type of plan may be forced upon the planner : and if we take this type of development to its logical conclusion we ought to cover the available land solidly with buildings, pump into them washed and filtered air and provide their occupants with artificial light. All the elements of this artificial environment are in fact already there in embryo. But, as that great sociologist Lewis Mumford has pointed out, it would be a sadly maladjusted social order that drove technical advance in these directions when, in point of fact, it could use science to solve its problems with greater economy and with more regard for basic human needs.

With the full opportunity to use the knowledge available, the ground-floor rooms of urban buildings—now so often the subject of right of light disputes—could reach standards of natural lighting comparable with those of rural areas. The regulation restricting the heights of buildings is clearly outworn. If, instead of this, it were possible to fix densities of population in relation to site areas, then it would be comparatively simple to demonstrate the plan types, the spacing and the heights of buildings to give the best all-round results. The same numbers of people could be housed, but they would enjoy better daylighting. Open space—which could indeed be green space—could be increased per head of population. The conception of the town as a series of streets flanked by cliff-like buildings would disappear and in its place could be set a picture of freely spaced buildings of varying heights surrounded by grass and trees.

Studies of daylight have gone further than this. For instance, if the desirable standards of daylighting in buildings were laid down (in the same way that the Home Office Regulations lay down standards of artificial light) the designer has available the necessary technique to see that these are secured.

The standards of daylighting for domestic rooms are already available. To assist designers in dealing with the multitude of common cases, simple tables have been published in which the performance of windows of different sizes and under varying degrees of obstructions, can be read off directly.[14] For more complicated cases other means of analysis—Waldram diagrams and Building Research Station protractors—are available.[15] It is perhaps worth noting, in passing, that recent publications in *The Lancet* have shown that germ counts and cross infection in badly daylighted hospitals are much higher than in those enjoying good daylight.

Equally important consideration could be given to the orientation of buildings and the placing of windows in relation to sunlight. This study was brilliantly advanced in 1933 when a joint committee, including scientific, medical and architectural representation, published a comprehensive report and illustrated instruments which could provide sunlight data simply and accurately.[16] One of these instruments, the heliodon, developed by the Building Research Station, can present, by the use of a model of the actual building, a visual representation of the effect of sunlight at any hour of the day and any time of the year. Alternatively, the sunlight results can be obtained by using special diagrams at the design stage. The scientific treatment of this subject is upsetting to conventional notions. It is commonly assumed that a wall facing due south must enjoy the maximum hours of sunlight. Actually, during summer months, walls facing south-east and south-west have more than half an hour's additional sun each day.

If the layout of the buildings has been laid down by daylight studies, here, then, is a means of orientating the buildings themselves so that every advantage can be taken of sunlight. In a recent war-time Social Survey carried out for the Building Research Station, nine out of ten housewives expressed a preference for sunlight in living rooms in the afternoons. On this basis the code of practice on the subject[17] lays down the limits of orientation and obstruction which will ensure that sunlight does in fact so penetrate under the worst possible winter conditions.

Some buildings should have maximum sunlight—others require shade. In hospitals, as Florence Nightingale recognised nearly a century ago, sunshine is required for its curative value and in schools, too, it is an important consideration : if contour lines are worked out to show the hours of sunshine

received internally, beds and desks can be correctly placed. Full sunshine for buildings would also have a marked effect in reducing warmth that would have to be artificially provided and would consequently have repercussions on the whole question of fuel conservation.

It is not out of place here to make a brief reference to artificial lighting. To a certain extent the history of its development in recent years forms a precedent for the improvement of standards of natural lighting. Artificial lighting can easily be measured. This knowledge is not new; well over a hundred years ago Count Rumford devised methods of assessing its intensity. The technique for assessing and controlling desirable standards of lighting was, therefore, available when, some years ago, the Home Office decided to insist on minimum levels of artificial light in certain types of building. The Home Office took this action as a result of an official inquiry into the effects of lighting on output and accidents; it has since proved well worth while on results to go on increasing the degree of light and consistently to raise these minimum standards. This development of improved standards has accompanied and perhaps stimulated a continuous research into the intensity of light required and the improvement of the illuminant itself.[18]

Perhaps the most interesting advance has occurred during the recent war with the widespread introduction in factories and offices of the fluorescent discharge tube. This form of illuminant has over twice the efficiency of the ordinary electric lamp, throws out only a quarter of its heat for the same intensity of light, and has a longer life. But its main interest rests in the completely changed principle of lighting which it suggests. The candle, the gas mantle and the electric bulb have one thing in common—they are all points of light. The fluorescent discharge tube produces its light by the action of an electric discharge on a fluorescent lining to the tube. It consequently creates an *area* of low intensity illumination, not a point of light. It therefore produces less glare and shadow. As its colour can be controlled during manufacture, it can be made to give a close reproduction of actual daylight. The new possibility now opening out for us is that artificial lighting may take the form of areas of highly efficient but diffused light with much of the character of natural light provided by the window itself. Any such development would certainly have to be guided by physiological factors, and the conditions required by the eye for comfort and clear vision, but here again useful evidence is rapidly becoming available.[19]

There is a possibility that this efficiency of lighting may be still further improved. A scientific writer has recently reminded us that the ordinary electric lamp gives off in light only 2·2 per cent. of the energy derived from coal. The firefly gives off light in a proportion to the energy consumed of 96·5 per cent. The substance which by a process of oxidisation makes this possible is known as luciferin. The laboratory production of such a substance would enable lighting to be practically 100 per cent. efficient, without any glare and by its absence of heat almost entirely without fire risk.[20]

(*c*) *Sound*

The problem of noise in towns and buildings has become increasingly more difficult to solve. Noise, on the one hand, though it may not have increased in intensity, has certainly become more widespread, so that we seldom get relief from it. Buildings on the other hand, have become lighter in structure and less capable of preventing the transmission of noise. Against these deteriorating conditions, however, we can set an increased knowledge of the whole question of sound.[21]

The subject can be divided into two sections —outdoor noise and noise transmission within buildings themselves. Among the sources of outdoor noise are road traffic, railways, some types of factory, and aerodromes. Noise generated from one point extends in a spherical wave front. As noise spreads from its source, the wave front constantly increases so that the energy in the waves is spread over a larger area and the loudness at any point is accordingly diminished. The reduction of sound out of doors is affected by several factors, such as warm and cool layers of air, wind, and so on, and is not amenable to exact calculation. It is possible, however, to give some general guidance with regard to distances of setting back buildings so as to reduce noise to a reasonable level. Further field-work might enable types of street to be classified from the point of view of noise, so that designers could take the necessary precautions. But the fundamental answer obviously rests in planning with its rationalisation of layout, its zoning of industrial buildings, and its separation of schools, hospitals and housing, from continuous sources of outdoor noise.

It is interesting to note that development of towns along existing lines can only lead to the worst possible result, as we have seen to be also the case from the point of view of sunlight. Streets lined with buildings only reflect and amplify sound apart from setting difficult problems of sound insulation in the

buildings themselves. If present-day land development, which tends to force these conditions, were to give place to the studied development of large areas of the town (as required also for the solution of daylight problems), it would be possible to achieve types of layout in which building blocks requiring quietness could be set back from noisy streets. These building blocks could be screened again by careful planting of trees, which, apart from their contribution to amenities, would act as effective sound barriers.

These are matters which require consideration by the planner. If they are not considered, any further precaution can only produce limited (though perhaps costly) results. If outdoor noise could be controlled the problem of indoor noise could then be tackled without prejudice. The sources of indoor noise are well known. The radio, flushing of w.c.'s, noisy hobbies, children, and many other things are contributory causes.

While these conditions are most notable in flats and multi-storeyed buildings generally, they are also prevalent in housing to an appreciable extent. The type of sound, the way in which a structure vibrates, and the paths by which sound can be transmitted have received careful and systematic study, and the results have been effectively summarised by Building Research Station workers and others.[22, 23] The sound-paths for any new structure can be identified, and although the resistance to air-borne sound depends primarily on weight, it becomes uneconomic to rely solely on weight to deal with modern noise sources—although it can be used up to a certain point. To deal economically with noise in modern building the principle of resistance through sheer weight has to be modified by the introduction of 'discontinuity' which can be achieved, for example, by such things as floating floors, double walls and suspended ceilings. When techniques of this kind are properly used, it becomes possible without unreasonable complication to obtain insulation standards from materials of normal weight, which in solid and continuous construction could only be reached by the use of heavy masses of masonry.

There is clearly a body of knowledge available on all aspects of comfort requirements—on how we should warm buildings, and light them, and give them freedom from disturbing noise. If this knowledge could be applied there is not the slightest doubt that it would change the aspect of buildings and improve out of all comparison our urban surroundings. But to be effective, this knowledge must, in the first place, be readily available. It is, fortunately, being embodied in the work of a Codes of Practice Committee which, under the aegis of the Ministry of Works, has already issued a number of draft codes. That is one important step. The other is to see that when rebuilding begins the knowledge is fully applied in practice.

III

How Shall We Build?

(*Materials and Methods*)

The conditions that we require for comfort and health depend in many ways on the siting and spacing of buildings in relation to each other. But they depend, too, on the structure itself. The building structure is the shell—the enclosure by means of which we achieve the conditions of comfort economically or wastefully, well or ill. We must, therefore, know very clearly exactly what the building structure has to do and what standard of performance is required from it. When this is known, we can select in the building structure the most desirable materials and methods. If the existing materials are not satisfactory, we can indicate the direction in which they might be improved or show the need for new development. But the materials and the structural system must also lend themselves to the most effective methods of production and erection. The subject consequently divides itself under three main heads: performance, materials, methods.

(*a*) *Performance*

What then are the functions of the various parts of the building structure? It might reasonably be expected that the various building regulations and by-laws would supply the answer. But this is in fact far from being the case. Although some regulations require definite standards in relation to strength, fire resistance, and so on, others used throughout the country rely purely on specified dimensions which have been based on traditional methods of building. Thus walls, for example, are required to be of a certain thickness. The varying thicknesses specified arise directly from the sizes of bricks. But they have no relation at all to what is exactly required from the point of view of strength or the degree of insulation that is necessary to prevent wasted heat. Quite apart from this, a regulation which states that a wall must be at least 9 ins. thick, for example, can prevent the use of a wall 6 ins. thick even if such a wall had a better overall efficiency.

The Building Research Station, on the other hand, has approached the whole subject from the angle of what the parts of the structure *have to do*.[24] This study has now

been developed to a point where the performance of all parts of the structure can be assessed on a scientific basis, and recent Government reports, drawing on such studies, have gone so far as to lay down the desirable performance standards for housing.

The categories of performance to be defined for buildings are strength and stability, resistance to moisture penetration, thermal insulation, sound insulation, fire-resistance and durability. The degree by which these standards can be accurately determined and economically achieved in practice depends in the main on scientific research.

The question of strength, for example, need no longer be confused with ' bulk.' The load to be carried by the building structure can be assessed and the strength required can be calculated. Until recently there were certain gaps in our knowledge that had to be covered by wasteful ' safety ' allowances. Recent research is filling these gaps by reliable scientific data : for instance, the study of wind pressures carried out by the National Physical Laboratory is one new advance. Another is the investigation of soil mechanics which includes such possibilities as the stabilisation of soil. The scientific data of this type which are now available provide the possibility of real economies in the structural framework and foundation design.

These economies are assisted by a more exact knowledge of the behaviour under stress of materials themselves. If, for instance, the effects of stresses on the material are known, the safe working stresses can be more exactly defined. This procedure has been assisted by the use of polarised light to demonstrate in model form the stresses set up in materials and of X-rays for the examination of the behaviour of welding. Statistical methods have been applied to determine the proportion of knots and other weaknesses in timber and in judging the average structural properties of laminated timber.[25] The techniques for dealing with a wide range of materials, including the new light metals, are available. The relative strength of materials in relation to their weights can be worked out and their most effective uses can be ascertained.

With the supporting elements of the structure exactly determined, its weather screening and insulating properties can next be considered. The supporting and screening elements of building are in fact quite separable entities, and it is by no means necessary to attempt to achieve these separate ends by the use of one single material such as brickwork. The load can be carried by a light framework of strong material such as steel. The screening element need be little more than a cover to this supporting framework, the materials used being selected for their special properties of resistance to moisture penetration and insulation. The effect of weather and atmospheric conditions on facing materials has been systematically studied,[26] and we know and can specify the degree of insulation required to maintain internal comfort conditions. There are also available impervious facing materials and highly efficient and lightweight insulating materials so that the problem of making an effective screening element can be readily solved. As the ways in which sound is transmitted in buildings are also known, this question also can be considered in the selection and assembly of materials.

Anyone who has noted how an occasional isolated building, or at least its framework, remains standing in an area destroyed by incendiary raids has in fact had an object lesson on the importance of fire resistance in building. Most of us are also more aware than we were in 1939 of the principal hazards—to the occupants, to the structure, and to surrounding property. The intensity of a fire will vary according to the contents of the building and its structure. But, if the combustible elements of any building are assessed and expressed in terms of the heat liberated, we can gauge the degree of fire resistance that will be required by the structure itself.[27] Research has shown how this can be done : if the contents of the building, having been expressed in terms of heat, can be shown to burn themselves out in one hour, the structure (again as a result of test) can be selected so that it will have more than one hour's resistance. Allowance will have to be made for buildings which have little combustible content but need increased resistance of structure because of the risk in human lives ; but this can be done with reasonable accuracy.

The result of this approach to the fire hazard problem is that structures can again be designed exactly and economically to meet certain known conditions and waste can consequently be avoided. By the careful spacing of buildings (which would automatically follow if we tackled problems of daylighting) the risk of the spread of fire from building to building could be practically eliminated.

How long should a building last ? That is the final question in assessing desirable performance, and it has two main aspects.[28] The first of these is the reduction of maintenance costs. In 1938 approximately 32·5 per cent. of the total annual building cost was devoted to maintenance, and it is safe to assume that much of this went into the patching up of property which was in any case structurally antiquated and obsolete from the point of view of meeting present-day needs. A considerable proportion of our building effort

must be wasted annually in this way. It need not be wasted if the problem was faced at the building stage. If this was done, we should have to recognise that buildings must be capable of change to meet changing requirements. The needs of schools, for example, are radically different from what they were in 1908, but the school built at that time was frequently built to last for a century or more. To meet this, we must build in such a way that structural methods will allow development or change as social requirements change. Systems of replacement of equipment or even the parts of the structure itself would eliminate the wasteful procedure of ' make do and mend ' and provide buildings capable of indefinite renewal. These things are not impossibilities, and the stage that has so far been reached makes it possible to indicate the way in which the question of building life should be answered.

If this new knowledge of all aspects of the performance standards of building structure is fully used, the way is clearly open to changes of both materials and methods. Let us consider for a moment their effects in practice. If, for instance, the standards suggested for house construction in the Government Report on House Construction are applied to the normal brick and timber structure, the following facts emerge.

1. The strength of the brick-built wall is in excess of what is really necessary, but its heat insulation value is too low.
2. Heating insulation values for the joist and boarded ground floor and the tiled or slated roof are also below the desirable level.
3. Sound insulation from floor to floor and house to house (as the case of semi-detached or terraced property) is inadequate.
4. The fire resistance of the wall is good, but that of the internal structure, floors and roof, is negligible.
5. The external, but not internal, maintenance costs are comparatively low, and the building has a long life—which is not necessarily in its favour.

These facts suggest obvious modifications of the traditional structure : could the strength of the external wall, for instance, be reduced and its insulation value increased by reducing its thickness and adding a lightweight insulated lining ? Alternatively, could the problems be solved with greater economy by using a completely different system of construction and range of materials ?

(*b*) *Materials*

It is impossible in these notes to give any idea of the range of building materials available and the extent to which scientific work has governed their development. In general, it may be said that the main technical change in the production of materials has been the increasing tendency to concentrate manufacture at centres remote from the site of building work, and to distribute by transport articles produced in quantities to the places where they are required. Fifty years ago, where the locality was favourable, even bricks themselves were often produced on the actual building site and many other materials were prepared and fabricated locally. But the concentration of scientifically guided production, which we have already noted in the case of steel, has by now gradually extended to many of the materials used in building.

This development has made possible the concentrated investigation and steady improvement of a product. Many manufacturers of building materials do, in fact, find it essential to employ a permanent staff of scientific workers for this purpose. Others, in addition to their own resources, have the benefit of the research initiated by the various Development Associations connected with particular industries—for instance, lead, copper, non-ferrous metals, and others. Still other materials, like plastics for example,[29] originate and are developed outside the strict confines of the building materials industries, but nevertheless find their way into building.

As a result of these advances, there was available, in 1939, a wide range of building materials. Traditional materials had been improved and sometimes were given new potentialities ; as in the case of timber, which in its plywood form had been given entirely new possibilities of application, or glass which had been toughened, made heat-resisting and ultra-violet transmitting in addition to being available for insulating purposes in the form of fibres or multicellular blocks.[30] Apart from this, many new materials and light alloys were being produced.

The initiative for all this development was in the main due to the manufacturers themselves. Side by side with it, the Building Research Station has steadily perfected the technique of testing and studying the properties of materials, and from this study come many of the facts which influence their selection in building. From testing also comes the guarantee of the quality of the product and the possibility of safeguarding the user by adopting a standard specification. British Standard Specifications are now available for many materials, and lay down their composition and manufacture and the way in which samples should be taken and tested.[31]

But the most far-reaching influence of science in the development of materials has still to make itself felt. For it is obvious that

a good deal of wasted effort can result if the development of materials is left purely to the manufacturers, who—until the need for national economy made it essential—had little indication of the possible scope of a product or its requirements in practice. Without this guidance there are clearly difficulties in developing production economically, and the development of a material without a wide knowledge of its possible application is bound to lead to some mistakes. This last difficulty is emphasised by the fact that it is a logical step to provide materials in the form of fabricated components ready for assembly on the site, and many parts of the building structure are supplied in this way.

A recent Government report has raised this very point with regard to wall and ceiling linings in which there has been a rapid increase in both range and type. While many of these materials are useful in their way, they do not possess individually the qualities desirable for the particular purpose of internal lining. One has good thermal properties but is inflammable, another is non-inflammable but brittle, several are made in different sizes of press so that they cannot be easily related to any standardisation of dimension in the constructional frame which in turn affects jointing, fixing, and resistance to impact in the lining itself. The desirable requirements might, of course, be achieved by a combination of materals, and this could easily be done during factory production but it would obviously require guidance as to exact requirements and probably co-operation between manufacturers.

Now it must be clear that, in the work of the Building Research Station on the performance requirements in buildings, we have in fact a valuable guide to the types of materials required and their desirable properties. If this knowledge became the recognised guide to the development of materials and components the potential savings to the industry would be immense. This guidance would put a limit on waste but it would not limit scope. Indeed it is possible that the clear knowledge of what is required might stimulate new lines of research, and it is in this direction that science has still so much to contribute.

(*c*) *Methods*

The fact that scientific methods of producing materials have developed coincidently with research work which is absolutely complementary (although often originating independently) is instructive. It indicates the way in which the trend of advances in different branches of work is governed by general forces and tendencies both inside and outside the industry, and we can expect to find that technical methods will have been re-orientated on similar lines.

The main technical change in actual building in the last half-century has, in point of fact, been the gradual transition from traditional craft methods to more highly organised and scientifically guided processes. But the picture that is presented at the moment is confusing. The traditional techniques remain and retain their influences on the new materials and systems that are being introduced. The result is that with the exception of some minor details the potentialities of changed methods have never been effectively realised.

In order to support this statement it is necessary to be clear about what might be achieved. We have seen that a wide range of building materials exists and that scientific research has laid down the desirable standards that should be reached in building. Now it is not at all difficult to show that we can, theoretically, achieve those standards by scientifically guided and exactly worked out structural methods. For example, it would be difficult to find greater exactness and economy of means than is to be seen in systems of construction in which the skin of the building itself is stressed so that all parts of the structure work at full efficiency. This is only one of a number of important structural advances.

From the point of view of production there has also been a marked increase in the number of factory-produced components used in building. It is possible, for example, to erect a building from units which are all factory-produced, and a good deal of faith is being vested in the completely prefabricated building as an answer to the national housing crisis. Prefabrication is one aspect of mechanisation ; but there are other innovations such as the greater use of mechanised plant and power-driven tools.[32]

It seems, therefore, that both the knowledge and the means are available to produce buildings economically and quickly. But if we turn to actual practice, it is impossible to find evidence that anything of this kind has been done in building as a whole, although we may find isolated examples.[33] Costs have continued to increase and the effects of new methods are completely lost. On the other hand, to depend upon traditional methods —which are incapable on grounds both of material and of man-power of producing the buildings we need in the next few years [34] —and to leave things to work themselves out, is a confession of failure. It is no way to meet a great national emergency.

This problem of building production has to be faced. When an attempt is made to

analyse the difficulties it becomes clear that the problem is not a technical problem at all. It is one purely of large-scale organisation. The real difficulties in the way of rapid technical and cost improvement are largely to be found in the complexities of building organisation as a whole.

The organisation of building built up by traditional development cannot meet the needs of the present situation. The building industry by its nature and origin is in any case highly dispersed. To this inherent complexity can now be added the extending ramifications into old and new industries specialising in the manufacture of materials, equipment and component parts. Within this confusing picture research workers, architects, builders and manufacturers all play their separate (and sometimes isolated) parts. Behind it all are methods of design, methods of ordering, methods of site erection and production that are tied to traditional practice. They are the methods of the craft but they are not yet the methods of closely integrated production as we know it in other fields.

The fact that so much remains to be done does, however, give opportunities for great improvements, and the way to reach these is becoming clear. We need, in the first place, to envisage the building programme and the available resources on a national basis as has in fact been possible during the war. Once this has been done the primary need is for concentration on those methods of building which will most effectively simplify problems of the supply of parts and the assembly of the structure itself.[35]

It is in the selection of these methods that science can make its most important contribution. We have seen that the scientific knowledge that exists has provided the means of meeting needs with the greatest economy and precision. During the war techniques have been developed not only for a scientific assessment of the optimum values of materials but also for balance and comparison of different structural systems in terms of materials and man-power. By this means the lines of building policy might be laid down.

Such work would have to take into account the mass production of certain components and the standardisation by means of which the necessary bulk ordering and simplification of site processes could be achieved. It would have to extend itself also into the investigation of site methods.

The whole tempo of building operations must be increased, and before it is safe to adopt new methods, or old ones, on a wide scale, we must have some certainty of our results. In order to do this it is necessary to adopt methods that are comparatively new to building—the full-scale experimental prototype and the scientific timing of all operations on this structure. This use of the prototype enables costly items to be recognised and simplified and site work to be properly sequenced. Costs can be accurately gauged and unproductive periods avoided.

The arguments for or against traditional method or prefabrication are beside the point. The main and immediate issue in building is the production of housing of the highest possible standard in the shortest possible time, and the concentration on a fundamental simplification in the whole process of building production is the urgent and immediate need. If we can achieve this on the basis of the scientific knowledge available we shall have achieved at once the closely knit organisation of research and production which is to be found in other industries, and which has resulted in increasing efficiencies and lowering costs.

Conclusion

When, in 1815, Sir Humphry Davy turned his attention to the problem of explosions in coal-mines, he secured samples of fire-damp (the gas involved), rapidly analysed its properties, and by brilliant application of this knowledge devised in three months a lamp that would burn in an explosive atmosphere without danger. George Stephenson was at the same time developing a solution separately by means of trial and error. There is no doubt that he would, in the long run, have achieved his object.[36] But his approach cannot be compared with Davy's, and the contrast is a typical example of the speed and sureness of scientific method. It also serves to emphasise the dependency of advances in technology on the development of scientific knowledge itself.

At the moment both these methods of approach are possible in building. We can use the traditional methods and adapt these in accordance with our experience, or we can use the new knowledge that has been gained by scientific advance. To do this will not be easy: but we can already see the lines on which such a development is taking place.

The urgent needs of war-time building have already forced the issue in certain directions. There has been, for example, a growing insistence on the use of research as a basis for actual practice. This is to be seen in the various Government reports on housing, for example, and in a marked degree in the work of the Codes of Practice Committee of the Ministry of Works. The main aim of this work is to produce a comprehensive system of codes of practice and by this means 'to

obtain in design the greatest practical efficiency in the fitness of buildings for their purpose, the maximum value from the labour and materials consumed and to act as a means of better co-ordination and co-operation within the industry.'

The draft codes that have appeared are based on scientific research and cover most of the subjects that have been outlined in these notes. If they become in fact the accepted codes, if they replace the outworn by-laws and building regulations, if their recommendations are carried into practice, there will be a rapid and fundamental change in our buildings and our environment. A change of this magnitude would clearly demonstrate that the contribution of science to building in the past few years has been by far the most important single factor in the improvement and rationalisation of all aspects of building development.

At present this will certainly not be generally accepted. Science is recognised as a means of testing materials or as a basis for structural calculation—but little more. What has yet to be generally realised is that the building industry is gradually making a change that has already been achieved in other industries. It is a more complicated change, but in essence it is no more or less than an advance in industrial method in which hand-craft method is being steadily replaced by more closely integrated production—empirical method by scientific approach. Most industries have passed through this stage of development which cannot in fact be achieved without an increasing use of science.

The pressure of this development is now so great that the whole field of building must be vitally affected, and changes are being forced from both outside and inside the industry. The growth of scientific knowledge has also reached a stage when it can be of the greatest use to building. The result of this can be a profound interaction : the technical methods of building can be changed out of all recognition by the application of science, and science itself will be rapidly expanded by problems arising from the building. The problems of certain materials and conditions of environment, for example, already call for rapid expansion of basic scientific research.

We have seen that the scientific knowledge that already exists covers many aspects of building work from general planning to methods of production. There is no doubt that, developed and co-ordinated, it could provide the general directing plan for the development of building on a national scale. Once the quantity of the building required has been assessed, the question of qualities is in many ways susceptible to a direct scientific solution. Requirements of fresh air, open space, sunlight, warmth and noise reduction can be surveyed and linked to questions such as the national planning of fuel and power, town planning, etc. When we know what is required it should be possible to state the means of achieving this with the greatest efficiencies of material and method.

Work on these lines can only be carried through with the strongest Government backing and with the support and co-operation of the industry as a whole. To secure the full benefits of science in building, it will be necessary to co-ordinate and develop a programme of research on a national scale. Such a programme would have to include :—

(*a*) An extension of research into general questions of planning and the space requirements and standards of towns and individual buildings.

(*b*) An extension of technical research in materials and methods with a view to studying problems of erection and guiding the development of materials by manufacturers.

(*c*) An extension of research into building organisation and costs.

(*d*) The development of basic research on such general problems as arise from the foregoing studies—for example, the development of new materials or problems of human comfort, etc.

But it is idle to suppose that this can be achieved without a struggle and that the mere setting out on paper of ideal organisations will produce results. The introduction of scientific method into building means change : and change means the overthrow of many practices and methods that are powerfully entrenched. But it is not too much to say that the provision of the buildings that are now required, both from the point of view of standard and quantity, depends almost entirely on whether that change can be accomplished. From the point of view of the public the position is, therefore, critical. The solution of their immediate housing need is dependent on the issue. The remodelling of environment and the re-creation of healthy surroundings in buildings and towns is again a question of whether we can use, as an instrument, the scientific knowledge that we possess.

It has been asserted that the increasingly dismal atmosphere of Victorian towns caused a type of moth to adapt its coloration to conform to its dingy surroundings. That was one effect of environment : another was the changing of men's fashions from colour to drab uniformity. But changes such as these are only the symbols of the effects of environment

on human lives. We have seen in the past our towns and buildings developed in such a way that the opportunities for health and comfort and a freer living have been depressed at every stage. We have also seen already the way in which this process might be changed. It can be changed, and towns and buildings can be the means of enriching human life if we are prepared to recognise—and use—the knowledge that exists.

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DOWN HOUSE DURING THE WAR

ON August 25, 1939, orders were given to close Down House to the public, to dismantle the Darwin collections, and to make provision for their safety. Precautionary measures were subsequently taken to support ceilings in some of the ground-floor rooms and the cellar ; and blast walls were erected.

The house was fortunate in escaping serious damage during the war. It is worth record that both the H.E. bomb and the V1 bomb which fell nearest to the house (the respective distances were 150 and 430 yards) failed to detonate ; though the H.E. bomb in question caused damage, as it had to be dug out and detonated *in situ*. Seven H.E. bombs fell on the Down House property during the battle of Britain, and 257 on the square mile of which the house is the centre. This last number does not include incendiaries, of which the nearest fell 20 yards from the house and, unobserved at the time, burned itself out in a flowerbed. During the period of the 'blitz' the not distant neighbourhood of an important military objective added to the risk to the locality : the plotting of craters on a map shows, by their relative density, that the enemy sometimes made attempts upon this objective, which itself suffered but rarely—a fact which supported other observations in maintaining a belief in the indifferent efficiency of the Luftwaffe. During the second attempt at destruction in London by piloted aircraft (1943–44) no damage was done in the neighbourhood of Downe. During the period of the V1 attack the fact that the place lay within the zone of one of the methods of defending London—the balloon barrage—made its position precarious, and the village was seriously

damaged by flying bombs brought down upon it, but the house again escaped lightly. No rocket bomb fell nearer than about three miles away, though on and just beyond that radius there were many, and the house was not infrequently shaken by what seemed, in distinction from the blast of H.E., to be earth tremors.

The injuries to the house and outbuildings consisted of broken glass in windows, the verandah, and the greenhouse, and a little damage to woodwork and to ceilings. There is no evidence of serious structural injury.

Though closed to the public, the utilities of the house in war time were not negligible. It was the headquarters of a platoon, and in the event of action might have been those of a company, of the Home Guard. As such it enjoyed the protection of a night guard, an advantage by no means to be ignored. It provided accommodation for a first-aid point, and the Association has received the thanks of the local authority for the facilities thus afforded. Officers and men of a searchlight detachment were billeted in the house for a few days in November 1940, and subsequently it was possible to offer some amenities to searchlight and balloon crews. When, on August 3, 1944, two flying bombs wrecked a number of houses in the village and damaged the official rest-centre, Down House afforded temporary accommodation to some thirty homeless persons.

The house staff was reduced during the war by the demands of national service, and is not yet fully restored. The rehabilitation of the house and grounds occupies its attention; in the present state of available labour this process must be slow. Nevertheless, the Darwin Memorial rooms have been reopened to the public (October 29), from 11 A.M. to 5 P.M. daily, excepting Fridays. Important additions have been made to the collection during the war. Among these are the notebooks kept by Darwin during the voyage of the *Beagle* and his MS. of the diary of the voyage, together with a number of other personal papers and possessions, which have come from members of the family; while Dr. R. Vaughan Williams, O.M., has presented Joseph Wright's portrait of Dr. Erasmus Darwin and other portraits. These additions and the rearrangement of the collection necessitate a new catalogue, but the reopening has not been delayed for the preparation of this.

The house committee has under consideration the possible uses of the property for appropriate purposes of research. That it should be so used was a wish of the donor, the late Sir Buckston Browne. One piece of research has been begun during the war, and continues—an experimental bed of *Lythrum salicaria* (purple loosestrife) is grown annually in connection with inheritance investigations undertaken by Prof. R. A. Fisher, F.R.S., and Dr. K. Mather. With a view to developments of this nature, and to the future adequate maintenance of the house and property in a condition worthy of its high object, the Council of the Association has decided that measures must be taken substantially to increase the endowment of the property beyond the sum given for that purpose to the Association by the donor: such increase will be a tribute to his memory only less than to that of Darwin himself.

SECRETARYSHIP OF THE BRITISH ASSOCIATION

The Council of the British Association have appointed Mr. D. N. Lowe as Secretary in succession to Dr. O. J. R. Howarth, who in normal circumstances would have retired in 1942. Mr. Lowe was assistant secretary before the war, during which he has served in the Ministry of Production; and he has not yet been released. Dr. Howarth has been asked to retain office until the next annual meeting of the Association, and if Mr. Lowe returns before this he and Dr. Howarth will act as joint secretaries. Dr. Howarth remains in residence at Down House.

THE BRITISH ASSOCIATION for the ADVANCEMENT OF SCIENCE

founded in 1831, and incorporated by Royal Charter in 1928, seeks to promote general interest in Science and its applications

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At its foundation, the objects of the Association were thus expressed: 'To give a stronger impulse and a more systematic direction to scientific inquiry; to promote intercourse of those who cultivate Science in different parts of the British Empire with one another and with foreign philosophers; to obtain more general attention for the objects of Science and the removal of any disadvantages of a public kind which impede its progress.'

Meetings, publications, and the encouragement and endowment of research are the chief methods by which the Association furthers these objects. It has thirteen Sections, dealing with the major departments of Science, physical, biological, and human. It has also a Division for the Social and International Relations of Science, which, during the war period, has held Conferences mainly concerned with post-war problems. These Conferences have in some measure replaced the great annual meetings of peace-time, which, under war conditions, it has been impossible to convene.

The transactions of these Conferences and reports on other activities of the Association are recorded in its publication The Advancement of Science, in normal conditions a quarterly, but at present appearing as occasion demands.

The Association maintains cordial relations with other associations for the advancement of Science, such as have been founded in America, Australia and New Zealand, South Africa, and India, and co-operates with many other scientific and official organisations both at home and abroad.

The funds of the Association are maintained by membership subscription. Full particulars of the work of the Association may be obtained on application to The Secretary, British Association, Burlington House, London, W.1. (Telephone: Regent 2109.)

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